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PERFORMANCE CAPACITY

— a Symposium

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PERFORMANCE CAPACITY

A symposium conducted by the

Nutrition Branch, Food Division

Quartermaster Food and Container Institute for the Armed Forces

and

Environmental Protection Research Division

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Edited by

Harry Spector, Josef Brožek, and Martin S. Peterson

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Opinions expressed in the symposium on Performance Capacity are those of the participants and do not necessarily represent the views or policies of the Department of Defense.

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PREFACE

"But wait a bit," the Oyster cried,
"Before we have our chat;
For some of us are out of breath,
And all of us are fat!"

Through the Looking Glass
by Lewis Carroll

We are cautioned today by responsible physicians and public health specialists that the physical fitness of the American population is alarmingly low — that reserve power is insufficient for occasional bouts of strenuous sport or work without the risk of physiologic embarrassment. That physical reserve capacity which is optional for the population as a whole becomes a critical necessity for military personnel called upon to perform maximally. Armed Forces drawn from such a civilian pool must, therefore, be conditioned to fitness and so fed, clothed, and supported that capability is sustained under the most adverse conditions. For obviously in a defense mission we cannot "wait a bit," the end of most fat oysters being lunch for those more fit.

The research efforts of the Quartermaster Corps in this regard are directed toward support of physical capability, for it is our responsibility to determine which foods will comprise a ration, when and how the man is to be fed, what he will wear, and how these factors relate to his required activity. As in any research problem, it is necessary to define the area of interest, to delineate the factors which are relevant, to select criteria which truly evaluate the phenomenon, to formulate hypotheses, and to develop methods suitable for assessment. Finally, it is required that observations be made and that conclusions be discussed in open court. It was to this end that the late Dr. Harry Spector, together with Dr. Austin Henschel, asked the National Research Council to convene a group of recognized experts for a free exchange of ideas, facts, and speculations pertinent to research into man's capability for physical work.

Upon the untimely demise of Dr. Spector, Drs. Josef Brožek and Martin S. Peterson graciously offered to edit the proceedings of that conference. A word of thanks should also be given to Dr. W. George Parks, Executive Director, National Research Council Advisory Board on Quartermaster Research and Development, and his staff for their yeoman services in organizing the conference. For their good efforts and those of the several participants we are indeed grateful.

Doris Howes Calloway
Chief, Nutrition Branch, Food Division
Quartermaster Food and Container
Institute for the Armed Forces

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HARRY SPECTOR (1915-1959)

IN MEMORIAM

The idea of the symposium on *Performance Capacity* was conceived one August afternoon during a long walk through the rolling countryside in the vicinity of New London, New Hampshire. The walk and the discussion that took place in its course was one of those extracurricular activities that make the Gordon Research Conferences so precious and that made them so dear to Harry Spector.

It may, then, be appropriate to cite in this *In Memoriam* the statement prepared at New London on August 20, 1959, some four years later:

"The Gordon Research Conference on Food and Nutrition pauses sorrowfully in its scheduled program to note and record the death of its 1957 Chairman, Harry Spector, and to convey to his family and professional colleagues its deep regrets at the loss of an esteemed co-worker and valued friend. His untimely passing, after years of devoted service to his country and his profession, leaves a void which all of us, in this conference, will feel in the years to come.

"The sciences of nutrition and food technology can ill afford the loss of one who so successfully joined their disciplines for the betterment of man. Past conferees will long remember, and future conferences miss, his cheerfulness, his astute comments and his ability to leaven the seriousness of a session with a twinkling eye."

J. B.

Proceedings of the Symposium

on

PERFORMANCE CAPACITY

I. INTRODUCTION

OPENING REMARKS

JOHN D. PETERMAN, COLONEL, QMC

Commandant, Quartermaster Food and Container Institute for the Armed Forces

The Quartermaster Corps of the Army and the Armed Forces in general receive a great deal of benefit from meetings of this kind. We look to our scientific and technical personnel for answers to problems of direct military interest. But we know that they do not have all the answers to the many food-related problems encountered in the performance of military duties, including the supreme duty, combat, and we don't even know all the problems. Our scientific and technical personnel must therefore look for assistance, at various times, from specialists outside the Department of Defense. I can assure you that seasoned members of the Armed Forces can recognize adequate or inadequate performance. They may not know what makes a good soldier from a biological or psychological standpoint, but they know a good soldier when they see him in action. In consideration of the increasing stress and strain of military operations, we need to have more fundamental data on performance. We need that data in order to be able to predict performance or to improve it. From this conference we shall derive, I am sure, some valuable guidelines for an effective appraisal of performance capacity, needed in developing and testing military rations.

Objectives of the Conference

JAMES M. ALLISON

Rutgers, The State University

New Brunswick, New Jersey

We on the Subcommittee on Nutrition, Committee on Foods, Advisory Board on Quartermaster Research and Development, are interested in performance capacity because of the experience we have had in the past in attempting to correlate the nutritional state of the individual with performance. During World War II, when we were studying the emergency rations, we set up some experiments which emphasized the interrelationship between nutritional state and performance capacity. These experiments brought out our lack of knowledge of what we really meant by performance capacity and how to measure it adequately.

For example, one of those experiments had to do with animals. We put some puppies on a diet that we felt would develop their lean body mass to a maximum and possibly keep their fat reserves at an optimum. We were trying to develop the ideal animal to measure performance capacity. The puppies grew into lean, active animals. Litter mates, grown on a diet which was somewhat deficient, developed their fat stores adequately and probably more than they should, but the lean body mass was abnormally low. They appeared somewhat hypothyroid. They were nice little animals, and many people picked them, in fact, for pets. They were not as active as the others. Their behavior and their performance capacity differed from that of their brothers and sisters who were being raised on the diet that developed the body stores in a different way.

Then we took some adult dogs and put them on a diet that again developed their lean body mass (their protein reserves) and certain other reserves maximally, or so we thought at the time. We placed another group on another diet, one that was more or less deficient in many respects, but nevertheless a diet that might be used by people. The animals became depleted in certain of their protein reserves. Then we put them on an emergency ration. Within 10 to 14 days the depleted animals were in trouble, whereas the others ate the emergency ration for a period of about 90 days before we could notice any loss in ability to perform. Again our measurements of performance capacity were inadequate.

I might mention one more experiment of this type, one that was very dramatic. We put some hamsters on a diet that we thought would develop them into ideal animals. They grew rapidly, and they certainly looked to be in excellent shape and performed very well indeed. Some of their litter mates were raised on laboratory chow made up of natural foodstuffs. They did not look to us to be in optimum nutritional state, and yet they seemed to be able to perform quite well. They were smaller and very active.

We brought both groups of animals into a disease state that we call "wet spot." Every one of the animals that we thought was in optimal nutritional state died within ten days. The animals on the lab chow did not even get sick; they continued active and healthy over this period of time. The disease-resistant factor was in the foodstuffs, I think — in the alfalfa meal,

or yeast, or some other constituent. The point is that a marked difference in performance capacity can be brought about by diet.

I am very much impressed by the data that Dr. Scrimshaw is getting in Guatemala, particularly with the children, on protein malnutrition. These children are tremendously depleted; in fact, they are so depleted that their gastro-intestinal tract is probably paper thin. The secretion of the digestive enzymes is very low, and yet their ability to utilize foodstuffs is remarkably good. Biochemically you might say that their performance *should be* very low, but when you give them milk proteins and so on they very quickly adjust in some way, biochemically, so that they are digesting those milk proteins. Recovery is remarkably rapid.

There is a great need to correlate performance capacity with our biochemical and physiological knowledge; in fact, it might be considered almost a new science that we need to develop if we are to determine just what the factors are that are involved in limiting performance. We feel that many, many of these factors are nutritional. Some of them, of course, can be associated with genetics, with emotional disturbances, and so on. But emotional disturbances, we feel, may be tied up, at times, with the nutritional condition of the individual.

The principal objective of this conference is expressed by the question that Dr. Spector put in his letter regarding the agenda of this conference: "How can an integrated index of fitness be developed to predict performance capacity?" This conference represents in a sense the prologue to a new science that we ought to be developing — a science correlating and integrating chemical knowledge with performance capacity.

Rationale of the Conference Agenda

HARRY SPECTOR*

Chief, Nutrition Branch

Food Division

Quartermaster Food and Container Institute

for the Armed Forces

Chicago

To make the most of this conference we should have an understanding as to the type of material that would be most useful under the various headings we have selected. We are starting off with "Body Functions Involved in Performance." We are not interested here in the basic physiology of the "normal" resting man. Our interest is in the changes observed during physical work and under other types of stress. An understanding of each of these functions will provide the basis for a better understanding of the applied tests that we now have and may suggest new tests that perhaps can or should be developed.

In the "Application of Standard Work Tests" we shall be emphasizing combined procedures rather than isolated tests. The emphasis is on the use of these various measurements as indicators of performance capacity, on methodology, and not on any data that have been accumulated. Which are the most useful tests? What are the limitations of a test? What new tests need to be developed?

In the last session, "The Effect of Environmental Stresses on Performance Capacity," we shall be considering findings. Again, however, we should keep in mind the principal objective of the conference, that is the appraisal of the practical value of specified tests for measuring the effects of environmental stresses.

To a person who has responsibility in the Air Force, "performance" will mean something quite different than it does to a Marine officer. We would find that our idea of performance capacity depends upon the tasks with which we are dealing. The one thing, however, that we are certain of is that, regardless of the uniform or the mission of the individual, we must consider performance capacity in terms of body functions.

*Deceased, August 14, 1959

II. BODY FUNCTIONS INVOLVED IN WORK AND THEIR USE TO PREDICT PERFORMANCE CAPACITY

OPENING REMARKS

AUSTIN HENSCHEL

Chief, Environmental Protection Research Division

Quartermaster Research and Engineering Center, Natick, Mass.

Most of us who are involved or who have been involved in studying what man can do under certain stress conditions, either controlled or uncontrolled, try to measure anything that is considered relevant and is convenient for us to measure at the time. We hope that some of the measurements we make, some measure of changes in the physiological or the psychological functions will give us a clue as to man's performance capacity. We hope that by measuring these end products we can get at what is happening within man — this integrated composite of numberless, highly differentiated individual cells.

Perhaps the things we have been measuring in the past yield quite insensitive indices of what actually is happening inside the intact individual. We have measured them, primarily, because they are the easy things to do. We have found that they change, but we also found that they frequently change only when one exceeds or approaches the physiological reserve of the man. Such measures give us very little indication of what is happening to the individual, within his normal physiological range of reserve. Most of these measurements give us very little information on what is happening to the reserve. Is the reserve shifting? Are elements of the reserve shifting in in respect to each other, or is the whole reserve process shifting?

Various things can happen to a man. His upper limit of reserve may decrease and his lower limit of reserve increase. The difference between the upper and lower limit, the whole thing, may shift up and down. All of these things in the end will probably be reflected in what the total individual in a particular situation will be capable of doing or what he will actually do in a particular type of situation.

In this part of the conference we shall take up the individual organ systems and say, "Let us look at their functions. What can we expect to learn by measuring the function of a system of an anatomical type in relationship to the total performance and capability of man?"

The cardiovascular system is probably the system that has been used most frequently as an index of the physical capabilities of man. How useful are cardiovascular tests as an index of true performance capability? Where are they useful? What are their limitations? In answering these questions we may think in terms of a specific performance, as for instance, running uphill five miles an hour on a ten percent grade, or ten miles an hour on a five percent grade. Or, if you wish, you may think in terms as general as the ability of the soldier who performs under simulated combat conditions for a week under arctic conditions. These situations are completely different as to the type of stresses placed on man; yet they are all stresses.

Many groups have made use of cardiovascular functions as an index of performance capability. Dr. Taylor, I know, has used them often. He will discuss the use of tests of the cardiovascular system in determining or predicting either performance capability in a specific sense or a general sense, or, conversely, as an index of the deterioration of capability that has occurred as a result of stress situations.

The Cardiovascular System as an Index of Performance Capacity under Stress

HENRY L. TAYLOR

Laboratory of Physiological Hygiene, University of Minnesota, Minneapolis

The Army, one assumes, will always have a foot soldier who will be called upon to walk long distances and carry a pack and a rifle. There will also be occasions when this man will have to do a 200-yard dash — or be counted among the dead or wounded. Most of what I have to say is based on the testing of the effects of various physiological stresses. To me the most satisfactory way of doing this is to study the same individual standard conditions under controlled stress and in recovery.

In regard to test equipment, we believe the treadmill — in an experimental situation, at least — has considerable advantage over the bicycle ergometer. A bicycle ergometer presents to the subject an unfamiliar type of work task. The average adult American has not developed and retained much skill in using a bicycle, and repeated bouts of work on a bicycle ergometer usually lead to substantial improvements in skill and the consequent reduction in energy necessary to perform a specified task. On the other hand, walking on the treadmill up a grade results in a very small increase in skill, and we feel that this is a very useful fact.

The work task we usually use is walking at the rate of three and half miles per hour on a ten percent grade. This requires a little over two liters of oxygen as a minimum and, in relatively well-trained men, yields a pulse rate of 130 to 140 beats per minute. We like to use work periods of one hour. My personal preference is to assign subjects who are to be tested in a specific regimen to do at least two one-hour periods of walking on the treadmill per day. If I might deviate a bit from the immediate subject, this procedure has some very useful features. The mere measuring of the time during which an individual is capable of carrying on this task gives you a good deal of information. When well-motivated men start to drop off the treadmill at the end of an hour and a half, you know you have a situation where deterioration has gone pretty far.

We put most emphasis on measurements made during work. These are pulse rate, respiratory efficiency, oxygen consumption used for calculation of mechanical efficiency, and rectal temperature (which of course is related to cardiovascular function). These measurements give you an index of the level at which steady state is being maintained, and failure to maintain a steady state is an obvious indication that fitness is reduced.

The second test we use is running, to establish maximal oxygen intake. We have standardized this test with regard to time and speed. We have found that many people cannot run very fast. The Harvard Fatigue Laboratory some years ago found that seven miles an hour was a very good compromise. You will find very few people who cannot run at seven miles an hour.

We have maintained this speed — seven miles per hour — throughout. If you start using nine or ten miles per hour you will find people in the

student body in the university or among volunteers from military establishments who simply cannot keep up.

We have kept the running time to three minutes because we wanted to make the test as short as possible and still get something pretty close to a maximal oxygen intake. If you ask men in a debilitated state to run for five or six minutes, you sometimes cannot complete your observations.

The test is independent of skill in running on a grade. You can prove convincingly the attainment of maximal intake by increasing the workload by either increasing the speed or the grade. This makes the procedure eventually independent of motivation since there is no self-determined effort involved.

Once you have established an individual's maximal oxygen intake, you can select the lowest grades that will elicit it. You use this situation not only for studying his maximal oxygen intake under stress conditions but also for measurements of the cardiorespiratory and biochemical responses of the individual to a fixed task.

Here, lactic acid measurements in the blood and oxygen debt, either partial or complete, are useful indices. The recovery pulse rate will also tell you something. Measurement of the pulse rate during the work is probably an additional useful index.

There are also the usual respiratory measurements of ventilation and respiratory efficiency — byproducts of procedures of this kind.

Finally, for some purposes we like to make use of the treadmill version of the procedure set up by Johnson and his colleagues at the late Harvard Fatigue Laboratory. This procedure has a self-determined end point. We have found this procedure useful in assessing the degree to which a man is willing to push himself, and, in the presence of good motivation, this is a good index of cardiovascular performance. We have also found the procedure very useful in assessing the "morale" of the subjects.

We have found these test situations to be sensitive to a large variety of stresses, including such things as bed rest, high environmental temperatures, caloric restrictions, experimentally induced malaria, and so on. It is useful, also, to be aware of the possibility of organ impairment. Since Dr. Simenson, in our Laboratory, is very much interested in electrocardiography and is willing to apply the technique at the slightest provocation, we have frequently taken electrocardiograms during recovery after exercise. We demand it if there seems to be any indication of arrythmia. This practice has uncovered a rather dramatic increase in the number of extrasystoles and premature ventricular beats in recovery from anaerobic work in the presence of dehydration and caloric restriction.

A word or two now about the general problem of the projection of the results of work of this kind, carried under controlled laboratory conditions, into practical terms. Dr. Henschel is probably right. We do not feel that these test situations represent an extraordinarily sensitive battery, but we are quite sure we can rank stresses in the order of their impact on physical performance.

There are situations in which you can predict with a certain amount of confidence that real-life performance is going to be very bad, and there

are other situations in which you can predict with a certain amount of confidence that performance will not be seriously interfered with. In the intermediate range, if the practical problem is sufficiently important, we believe the results should be investigated and validated in field tests..

Circulatory-Respiratory Response to Physical Work

BRUNO BALKE*

Department of Physiology-Biophysics, School of Aviation Medicine, USAF Randolph Air Force Base, Texas

Physical performance capacity has two components: anaerobic and aerobic. For work of longer duration the metabolic requirements have to be matched by adequate supplies, first of all, of oxygen.

If, in brief, maximal anaerobic work shortcomings in local blood flow or limitations of general circulatory and respiratory functions restrict the oxygen supply, continuation of work depends on the local or general capacity of the tissue to incur oxygen debt. This parameter of physiological adaptability cannot be defined precisely and depends, to a great extent, on psychological factors such as will power, tolerance for pain, dyspnoea, or for other kinds of discomfort.

On the other hand, the aerobic work capacity may furnish a reliable criterion of an individual's performance capacity, quantitatively. The mode of circulatory-respiratory responses to given work intensities may allow for qualitative evaluations of performance capacity.

These principles, already pointed out by Dr. Taylor in his previous comments, are generally accepted by all performance physiologists (1). Only the methods used by the various investigators differ, and they differ widely. It is not the purpose of these comments to review critically some of the most promising test procedures in use but to add to the confusion by presenting another testing procedure successfully employed in several studies (2, 3) of work capacity at the Laboratory of Performance Physiology of the School of Aviation Medicine, U. S. Air Force, Randolph Air Force Base. This Work Capacity Test measures in a single experimental trial of relatively short duration the circulatory-respiratory responses of an individual (or animal) to physical work within the entire range of his aerobic work capacity, and beyond, if so desired.

Work Capacity Test. For accurately defined physical work the motor-driven treadmill or the bicycle ergometer is used, preferably the former. Energy expenditure, or a low initial level at the beginning of the test, is gradually increased in small amounts up to the maximum attainable level. That is accomplished by elevating the treadmill angle in one-minute intervals by one percent while the speed is kept constant at 3.34 m.p.h. (or 90 meters/minute).

Pulse rate and blood pressure are measured by the auscultatory method, using a mercury sphygmomanometer for determining the pressure over the brachial artery. The measurements are taken in rest, work, and recovery. During exercise the arm-cuff is inflated at the beginning of the second half of each minute, seconds later systolic pressure is determined and called out for recording. Immediately thereafter the pulse rate is counted during a period of 15 seconds and, while the pressure is slowly released, the diastolic pressure is measured at the end of the pulse count. This procedure is usually completed within 25 seconds. The test serves as the best objective indicator of a subject's circulatory reserves.

The pulmonary gas exchange is measured continuously or at frequent

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intervals, e.g., by monitoring the expired gas concentrations continuously by proper instrumentation, recording simultaneously the ventilatory volume; or by collecting the expired air in Douglas bags with subsequent gas analysis and determination of the gas volume exhaled.

Test Criteria

With rising work intensities pulse rate and systolic pressure increase. The slope of the pulse rate curve varies from individual to individual and also within the same experimental subject, depending on the state of physical condition. Usually, the systolic pressure reaches a peak at a workload at which a pulse rate is close to 180 beats per minute. If this pulse rate is exceeded, the systolic pressure, in most instances, drops off. Frequently, at this point, the diastolic pressure rises slightly. This fall of the systolic pressure and or rise of the diastolic pressure may indicate an imminent reduction of the cardiac stroke volume and, in consequence, impending exhaustion of cardiac reserves. That is furthermore borne out by the measurement of oxygen consumption: at work intensities causing an acceleration of the pulse frequency beyond 180 per minute the oxygen intake tends to level off.

Another criterion of the limit of aerobic work capacity at the time at which the pulse frequency exceeds "180" appears to be the respiratory gas exchange ratio: approximately at this time the output of carbon dioxide overtakes the oxygen consumption, indicating insufficient oxygen supply to the working muscles. The lactic acid level of the blood also points to this failure of coping with metabolic demands. While work, calling for pulse rate responses up to 160 beats per minute, can be accomplished with only slight increase of blood lactic acid, the work intensities leading to pulse rates of 180 per minute and beyond result in lactic acid values of 70-80 mg. and above. These are values postulated by Åstrand (1) as criterion of a sufficiently high level of work in tests designated to study maximal oxygen consumption.

The ventilatory efficiency (oxygen intake related to ventilation) and the "oxygen pulse" (oxygen intake related to pulse rate) can be used to evaluate performance capacity qualitatively.

Simplified Work Capacity Test

The oxygen consumption determined during Work Capacity Tests on a large group of individuals was found to be fairly constant at any given workload when the body weight was taken into consideration. Ninety-five percent of the values of oxygen taken up per kilogram per minute were for each workload to 95 percent within a range of ± 10 percent. Such a spread of results can readily be accounted for by technical inaccuracies as well as by variations in the ease or tensions of the individuals walking on the treadmill.

The increase in oxygen consumption was almost a linear function of the increase in work performed. On the average, 1.8 ml. of oxygen were consumed per minute for the performance of one meter-kilogram per minute. For the theoretical estimation of oxygen costs during treadmill work the following empirical formula proved to approximate most closely the actual data:

$$\dot{V}_{O_2} = v \times w \times 1.8\ (.073 + \frac{\alpha}{100})$$

where $\dot{V}_{O_2}$ is the estimated oxygen consumption in ml./min.

v is the treadmill speed in meters/min.

w is the body weight in kilogram

α is the angle of the treadmill in percent

.073 is the factor most closely assessing the vertical lifting of weight during horizontal walking.

There was a close agreement between actual measurements of oxygen consumption during the Work Capacity Test or during steady state work and the oxygen consumption estimated by means of this formula. That is demonstrated in table 1 in which the actual oxygen consumption values obtained in ten different subjects during steady state work on the treadmill (speed: 91 m/min., angle of treadmill and duration of work as indicated) are compared with the predicted values.

These findings may justify a simplification of the Work Capacity Test in studies with large experimental groups. Respiratory measurements may then be excluded from the testing procedure and the test evaluation may be based entirely on the interrelations between work intensity, represented by test time in minutes and/or by the degree of treadmill slope in percent, and pulse rate. Any fixed pulse rate could be chosen as the cut-off point. The pulse rate of 180/min. is suggested because it represents most closely the upper limit of adequate oxygen transport. The simultaneous determination of blood pressure is indicated as a safety factor; a definite reduction in pulse pressure might become the objective signal to terminate the testing of such an individual whose maximal pulse rate is less than "180."

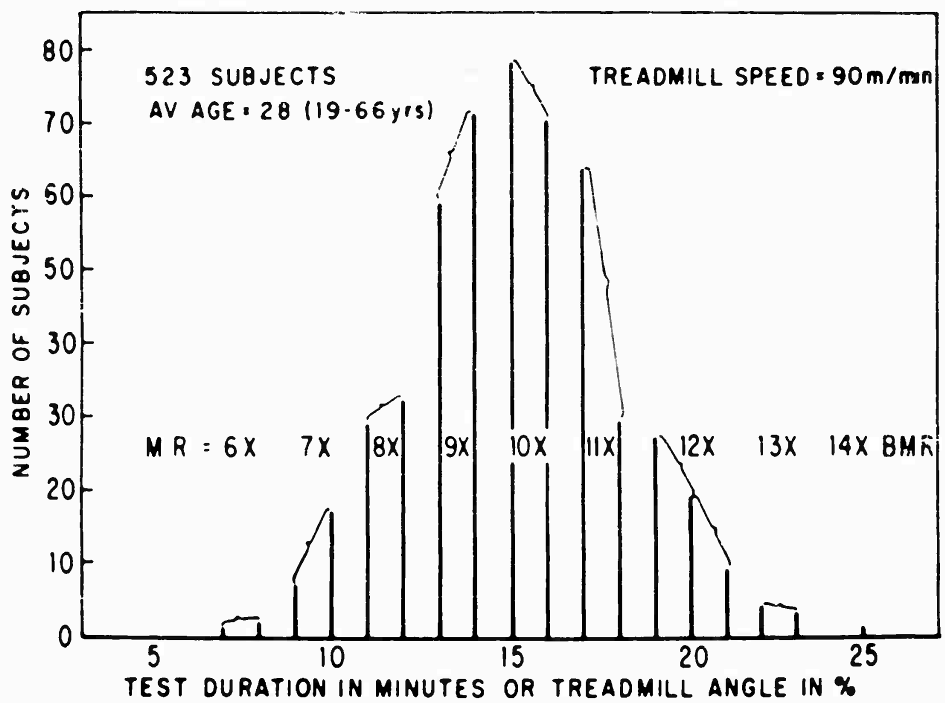
Evaluation of the Work Capacity Test

The distribution of test results obtained in more than 500 "healthy" male individuals, 19 to 66 years of age (mean: 28 years), is shown in figure 1. It is felt that this study represents a fairly realistic cross section of the American male population and that it can be used as a basis for establishing a classification scale of physical performance. Such a scale is presented in table 2. It is based, principally, on the individual's ability to cope aerobically with metabolic requirements in multiples of the basal metabolic rate. The peak of the bell-shaped curve in figure 1 suggests that the physiologic capacity for tenfold increase of the B.M.R. represents a "normal" or "average" work capacity. Although the other indices of physical working capacity were chosen arbitrarily, they might be adequate at least in the upper scale range where it was found that only individuals regularly engaged in physical activities of high metabolic demands scored as high as 12 times the B.M.R. or better.

The physical performance tested by the Work Capacity Test may appear to be unrelated to the work capacity defined by the size of metabolic reserves. A more recent study, however, has shown that experimental subjects in the upper range of work capacity had greater carbohydrate reserves than individuals who performed poorly. As an illustration, table 3 shows the oxygen consumption in ml./kg/min. at the pulse rate of "180" during the Work Capacity Test and the total caloric expenditure (as well as average RQ, and estimated carbohydrate reserves) during prolonged steady state work, towards exhaustion. Both tests were performed by ten subjects before

Figure 1

The distribution of the work capacity of 523 male individuals, determined by the Work Capacity Test as time (or % angle) until a pulse rate of "180" is reached. The metabolic requirements of the crest load are indicated as approximative multiples of the basal metabolic rate.



and after a 10-week course of physical training. During the pretraining period, the work intensity in the prolonged steady-state test was equivalent to 75-80 percent of the peak metabolic requirements in Work Capacity Test.

Several other distinct differences in fat, carbohydrate, and protein metabolism also indicated that the Work Capacity Test not only evaluates cardio-respiratory adaptabilities but physical performance capacity in general.

TABLE 1

Average oxygen consumption during steady state work on the treadmill (speed: 91 m./min., angle of the treadmill and duration of work as indicated) compared with the predicted values of oxygen intake.

Subject	Weight kg.	Angle %	Duration min.	Oxygen Consumption Measured ml./kg./min.	 Estimated
1	75.0	18	30	3152	3105
2	84.5	16	30	3245	3220
3	68.3	14	120	2660	2640
4	83.5	13	30	2870	2780
5	86.7	10	60	2415	2440
6	75.5	10	30	2155	2135
7	76.0	9	90	2168	2030
8	82.6	9	60	2155	2185
9	73.5	7.5	30	1820	1835
10	86.7	6	60	1980	1910

TABLE 2

The evaluation of physical performance capacity by the Work Capacity Test relating the critical test time (or percent of grade), the metabolic costs, and the empirical rating.

Minutes (or %-Angle)	O_2-Intake at "180" ml./kg./min.	Metabolic Requirements in Multiples of B.M.R.	Performance Rating
- 8	-25	-6 x	pathologic
9-10	25-28	7 x	very poor
11-12	28-31	8 x	poor
13-14	31-35	9 x	fair
15-16	35-38	10 x	normal or average
17-18	38-42	11 x	good
19-21	42-47	12 x	very good
22-23	47-52	13-14 x	superior
24+	52 +	14 x+	excellent

TABLE 3

Oxygen intake during relatively short-term aerobic work capacity is compared with the total energy expenditure during steady state work towards exhaustion, both before (I) and after (II) a ten-week period of physical training. During pretraining the average test time at the pulse rate of "180" was 15 minutes and in the steady state type of test exhaustion occurred after 115 minutes. Post-training the test duration averaged 20 and 145 minutes, respectively.

	Work capacity test		Prolonged steady state work towards exhaustion					
Subject	O_2-intake at "180" ml./kg./min.		Total Caloric expenditure 115/min 145/min		Average RQ		Carbohydrate reserves g	
	I	II	I	II	I	II	I	II
1	44	52	1420	1810	.955	.956	291	373
2	42	49	1315	1725	.921	.963	231	374
3	41	48	1645	1850	.918	.953	284	377
4	43	47	1600	1780	.889	.945	236	348
5	36	45	1360	1560	.935	.947	256	310
6	35	41	1440	1580	.902	.961	226	332
7	33	42	1365	1650	.92	.922	238	292
8	32	46	1410	1620	.89	.915	210	276
9	28	37	1225	1540	.881	.904	173	248
10	34	38	1410	1630	.79	.857	89	197
Average:	37	45	1419	1653	.9	.932	223	312

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HEART RATE

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As a footnote to the elegant presentations of Dr. Taylor and Dr. Balke, I should like to comment briefly on the use of the heart rate in tests of performance. Sometimes the heart rate is the only convenient objective measure of effort. Often the work stress is combined with heat stress and the heart rate responds to both stresses. Here heat may be the primary factor limiting performance.

An example of the use of heart rate under these conditions comes from the evaluation of protective clothing from the standpoint of the limitations it imposes on the performance of work in the heat. The suits were nearly equal in resistance to the passage of sensible heat but varied in resistance to the passage of water, ranging from that of herringbone twill to that of rubber-coated fabric. Previously we had made comparisons of work performance in terms of a composite physiological strain index including heart rate, measured at the end of a fixed treadmill task (4, 5, 17) or at an endurance end-point (7). This method was sufficiently discriminating. A test involving a treadmill task of progressively increasing intensity was tried briefly (7, 18). One drawback of these two types of test was the difficulty of translating the results into predictions of performance in the field, although one method of prediction was suggested (15). In order to overcome this objection a test of endurance was tried with a subjective end-point verified by measurements of strain. The details of this test have been published elsewhere (8, 14, 13, 9) and some of the results will be presented later.

In one phase of the work the heart rate was used to verifiy the tolerance time in minutes, (Tm) of two subjects. The tolerance time varied according to the suit worn, the temperature (22° to 38°C), humidity (10 to 24 mm Hg vapor tension of water) and the treadmill speeu (2 or 3 mph). The heart rate was recorded at 5- or 10-minute intervals. From these data the best fitting curve of heart rate versus time was calculated; the time required to reach a heart rate of 160 was read from the curve by interpolation. The close correlation between the time to reach a heart rate of 160 determined in this way, and the voluntary tolerance time, is shown in figure 1. The rate of 160 was chosen because it was just below the highest reached in all the tests. However, in the complete series of six men the average final heart rate declined from 180 for a tolerance time of 25 minutes to 160 for a tolerance time of 125 minutes.

Two kinds of limitation on the use of this procedure in other circumstances will be discussed. In the first place, it is recognized that the heart rate is influenced by the intensity of work and the heat stress. For the resting condition and much higher environmental temperatures, the end of voluntary tolerance was reached at a lower average heart rate than in work (3, 7). This figure comes from data of Blockley and co-workers (1, 2, 3) summarized in reference (9) and in a later presentation.

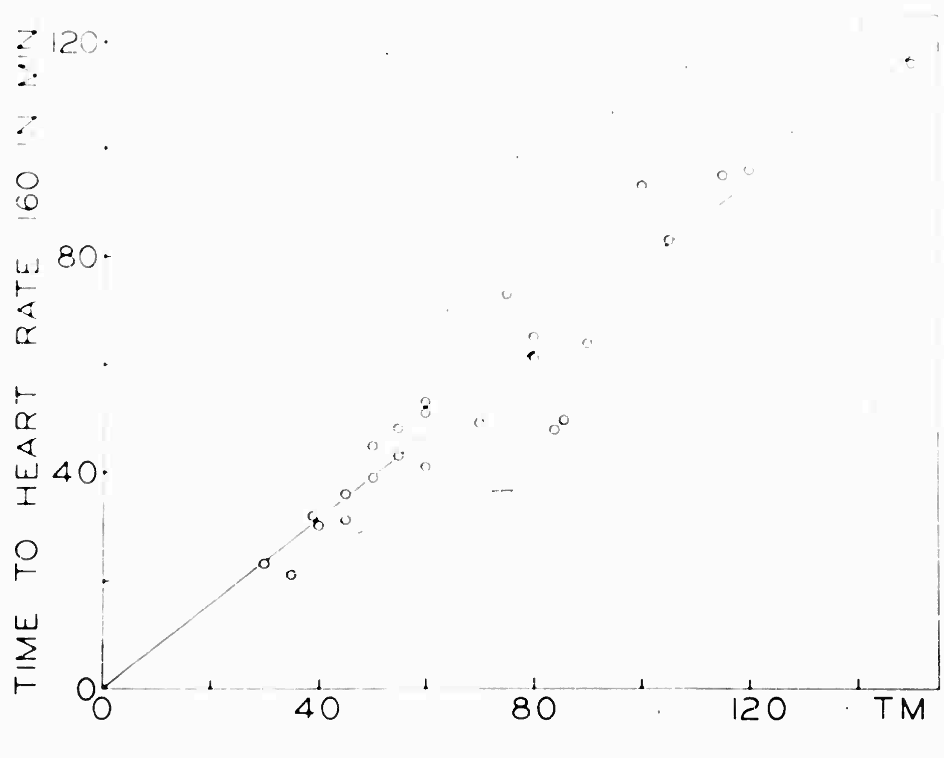
TABLE 1

Effect of atropine on the heart rate during moderately hard work. Data of Sid Robinson (16). Average data for 3 men walking for 16 minutes at 3.5 mph up an 8.6% grade at a temperature of 26.4°C dry bulb and 20.4°C wet bulb, with and without 2 mg of atropine sulphate.

	Control	Atropine
Oxygen uptake, l/min.	1.99	2.03
Ventilation, l/min.	38.6	39.0
Blood lactate, mg %	21.	20.
Pulse, per min.	134.	166.

Figure 1

Voluntary tolerance time in minutes (Tm) and time to reach a heart rate of 160. Individual experiments on subjects to D and S. Taken from Figure 4 in reference 9.



In the second place, other specific influences on the heart rate must be excluded. An example is atropine. Because of its use in the treatment of casualties from anticholinesterase agents, the effect of atropine on the ability to perform muscular work has been of considerable interest to those concerned with chemical warfare (10, 6, 16, 11, 12).

Perhaps the most pertinent illustrative data are contained in a report from Dr. Sid Robinson's laboratory (16). In moderately hard work in a cool environment, (Table 1) 2 mg of atropine sulfate markedly increased the heart rate without affecting the work capacity measured in terms of pulmonary ventilation, oxygen uptake, or lactic acid accumulation in the blood.

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DISCUSSION OF CARDIOVASCULAR FUNCTIONS

Henschel: The meeting is now open for discussion of the tests of the cardiovascular and respiratory systems. It is probably going to be impossible to keep them separate as methods for measuring work capacity or total operative effectiveness of the individual.

Dr. Balke, what were the conditions under which your studies were done? Did you have a controlled environment?

Balke: All studies were done in an air-conditioned laboratory at a temperature of 22° to 23° C. Concerning the factor of anxiety, it should be mentioned that each "newcomer" is given first a few minutes of a practice walk on the treadmill until he becomes entirely relaxed and familiar with the treadmill. During the gradually increased work, especially at the higher levels of work intensity, we have never observed changes in pulse rate or pulse pressure which could not be accounted for by the changes of workloads.

Henschel: What happens in the case of a different type of anxiety — when the individual, during his walk, gets to the point of actual danger to himself?

Balke: This type of anxiety has not been observed in our studies. It should be kept in mind that the subjects are not forced to proceed towards a point of exhaustion. Everyone may hold on with the hands and step off the treadmill whenever he feels that the work is exceeding his capacity.

Henschel: Dr. Balke, didn't the measurements of blood pressure under work situations turn out to be unreliable?

Balke: We consider the normal procedure of measuring blood pressure during work on the treadmill or bicycle ergometer as sufficiently reliable and the results obtained as most valuable in assessing hemodynamic efficiency.

Johnson: You use the categories of "good," "bad," and "indifferent" in interpreting results, but I didn't hear you specify anything concerning age, sex, or previous condition of servitude In other words, is it fair to say that a 60-year-old woman is in poor shape because she is not pushing herself up this high?

Balke: If, in general, work capacity is defined by the maximum of metabolic demands which can be dealt with, adequately and aerobically, through adaptive mobilization of all the physiologic reserves, this capacity might not, necessarily, be affected by age and/or sex to a too great extent. The differences in the ability to cope with such metabolic requirements appear to be adequate indications of the physical conditions at hand. Regarding the example mentioned: a 60-year-old woman *might* be in "better shape" than a boy just entering college.

The results obtained from a rather large group of male individuals within the age range of 19 to 65 years demonstrated clearly that work capacity must not necessarily decline, with progressing age, to a "subnormal" level. Generally, the amount of physical activity throughout the life span affects physical performance most.

Young: I am not certain about one thing. Dr Balke indicated that

during certain conditions such as blood loss and so on there is a decrease of 10 to 20 percent in work capacity. Is that measured by oxygen uptake, running time, CO_2, pulse, or what?

Balke: Many investigators have reported the existence of a direct relationship between work intensity and oxygen consumption. Our studies, involving bicycling, running, or grade walking, were no exception to this generally accepted concept. On the contrary, we feel encouraged to add that the amount of oxygen required to perform a given unit of work is so constant that we might be able to estimate the footpounds or meterkilograms of work output from the oxygen intake during any conditions of rest or work.

Young: This is true for the healthy, normal individual. However, under certain conditions of nutrition, the pulse rate might drop and the oxygen consumption might remain relatively constant.

Balke: I would say the oxygen consumption will always be related to the work intensity. However, the pulse rate is a measure of quality. The oxygen consumption is a measure of quantity.

Grossman: I believe Dr. Taylor feels that the maximum oxygen consumption is a relatively good measure of performance capacity. Under conditions of training, where you find an improvement of maximum oxygen consumption, is this accompanied by a corresponding increase in the load required to produce the maximum output? It would seem to me that that would have to be so.

Taylor: I don't think we are measuring quite the same thing, although in examining the results in any specific situation it could very well be that we would come up with the same answer.

We find under the specific conditions under which we are working that there is quite a wide range of maximal oxygen intakes at a specific workload. There will come a time, if you produce tremendous improvement in your individual, when you have to go to a higher workload. I am not certain, particularly in a training situation, why this is. Some of this is due to the factor of skill. While walking on the treadmill he is not subject to improvement in mechanical efficiency to any great degree. It is my impression that in grade running on the treadmill he is.

Brožek: You have the neuromuscular component of coordination, which is variable.

Taylor: There is a very rough relationship between workload and maximal oxygen intake, but there are wide differences within the same load.

Grossman: That is in Dr. Balke's 10 percent? Is it all included in that?

Taylor: Well, I suppose this is something that should be examined. It seems to me that Dr. Balke could be stopping his subjects before they reach maximal oxygen intake. I wanted to ask him whether he had any measurements of rectal temperature. Do you find an ever-increasing rectal temperature over the 30 minutes?

Balke: After a slight dip in rectal temperature at the beginning of the work, we observed a steady increase of body temperature from 38° to 38.5° C. at the end of the test.

Henschel: Dr. Balke, would I be correct in stating that if we stripped

your test of everything except the most fundamental things, and if you had a measure of the pulse rate by your increasing step test, and did ventilation volume and calculated oxygen consumption, you actually then would have the basic data that were required for giving an index of the capabilities of the man — a means of classifying him according to performance capability?

Balke: The permissible simplification of the testing procedure was already described. A further simplifying would be against the concept held by most investigators that work capacity has to be tested under working conditions involving crest loads. Of course, after a few minutes of work, an experienced observer could extrapolate work capacity from the early observations made, but such an extrapolation would not be accurate enough for comparative studies in the laboratory.

Vogel: Going back to Dr. Henschel's question, when he asked for a short test criterion, I wonder whether some test of exposure to a known amount of carbon dioxide could not be a short test of a person's condition and work capacity?

Balke: Condition, not work capacity. Keep work capacity as work capacity. It might be an indication of some performance, but not work capacity. We want to know the work capacity of patients under normal and other conditions, and therefore we have to run through this test, which is very short if you compare it with many other procedures. Here you get it all in about 20 minutes. You have to employ severe workloads, otherwise you won't get the correct results. Even up to pulse rates of 160 it might not be enough.

THE SYMPATHICO-ADRENAL SYSTEM

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Our experience with the endocrine system is limited to the responses of the adrenal gland. The data are concerned with the evaluation of the pituitary-adrenal and the sympathico-adrenal systems. These systems are of the utmost importance with respect to stress and performance capacity (19).

The evaluation of the sympathico-adrenal system is achieved by measuring the excretion of epinephrine (E) and norepinephrine (NE). Other participants in this conference are also concerned with the sympathico-adrenal system. Certainly, oxygen consumption, lactic acid formation, systolic and diastolic pressure, and pulse rate are directly related to the secretion of the neurohormones, E and NE (12).

The pituitary-adrenal system may also be studied by the measurement of hormones excreted in the urine. In this case we are concerned with the steroids secreted by the adrenal cortex and their metabolites. Two classes of steroids give information in this regard: (1) C19 steroids: compounds having 19 carbon atoms, the 17-ketosteroids (17-KS), and (2) C21 steroids: compounds having 21 carbon atoms, the 17-hydroxycorticosteroids (17-OHCS). More recently the estimation of aldosterone excretion which is achieved principally by bioassay has been added to the steroids involved in stress (13, 21).

In the study of the endocrine system the biochemical measurements may be concerned with the hormones secreted by the glands and their metabolites or with the effects of these hormones on other various physiological processes — e.g., electrolyte metabolism, carbohydrate and protein metabolism. Our discussion will be limited to the hormones excreted by the glands concerned and their metabolites. We should emphasize that the state of these other physiological systems influences the functional capacity of the endocrine system. The functions of the pituitary-adrenal system are governed by the state of carbohydrate, protein, and electrolyte balance of the organism as influenced by dietary regimes, and the neurohormones of the sympathico-adrenal system are dependent on such amino acids, e.g., tyrosine, for their ultimate biosynthesis (10).

The adrenal gland, consisting as it does of two separate hormonal systems, is concerned directly with stress and performance capacity. The functional relationship of each system to the other has been a matter of great interest in the past 20 years, but to date our knowledge regarding this relationship is quite limited (14, 17).

Since a discussion of the pituitary-adrenal system will be presented

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later. I will confine the rest of this presentation to the evaluation of the sympathico-adrenal system as achieved by the measurements of urinary excretion of E and NE.

Method. Urine was extracted by the alumina absorption method of von Euler and Hellner (23). The maximum efficiency of this method is 70-80 percent, based on recovery data. The bioassay was performed by a modification of the method described by Gaddum and Lembeck (8). This method consisted of testing a sample on the rat colon for NE and the rat uterus for E. The bioassay is based on the quantitative inhibition by the catechol amines of the contractions induced *in vitro* in a 2-cc. bath with acetylcholine (7, 9). The inhibitions of NE and E are approximately equal when tested on the colon; but when tested on the uterus, E is 75 to 300 times more potent than NE. The colon assay was used when rapid estimates of total (NE + E) were desired.

Nature of Epinephrine and Norepinephrine in Normal Human Urine

Holtz *et al.* (12) using acid hydrolysis, demonstrated the presence of a pressor substance (urosympathin) in the urine of normal man. Closer examination of the urine extract indicated that this pressor substance was a mixture of E, NE, and the relatively inactive hydroxytyramine (23, 22). von Euler and associates (22) separated these amines by means of chromatographic techniques and showed that the normal amounts of these substances were 0.1 - 0.2 mg. per day for hydroxytyramine, 20 - 60 g. per day for NE, and 1.0 - 8.0 g. per day for E.

Studies were undertaken to examine some of the properties of the NE and E present in human urine (5) by (a) acid hydrolysis, (b) -glucuronidase hydrolysis, and (c) incubation with Mylase P which was used as a source of phenolsulfatase.

Table 1 presents the data of seven experiments in which four one-hour urine aliquots were taken from each urine sample. One aliquot was extracted directly; the second, third, and fourth were acidified with sulfuric acid to pH 1.5 and boiled for 5, 15, and 30 minutes, respectively, and then extracted after rapid cooling. Experiment No. 335 represents the data on total E and NE which were obtained by the rat-colon assay. All other experiments were carried out on both the rat uterus for E, and the rat colon for NE. It may be noted that acid hydrolysis increased the NE titer after 5 minutes of boiling; there was little loss after 15 minutes of boiling; but 30 minutes of boiling resulted in the loss of up to 50 percent compared to the high values obtained after 5 minutes of boiling. The E appeared to be mostly free. Experiment No. 489 shows an increase in measurable E after 15 minutes of boiling. Though the increase in amount was smaller percentagewise, it was appreciable.

Table 2 presents data of the NE and E after one percent -glucuronidase hydrolysis. This consisted of adding sufficient enzyme to the urine to make a one percent solution and then incubating at pH 6.5 for two hours at 37° C (20). All samples were equivalent to a one-hour excretion of urine. There was a marked rise in the measurable amount of NE. The E remained the same, indicating that it may possibly be free or at least not a glucuronide. The further qualification may be made that these assertions are limited to the period of incubation used.

TABLE 1

NE AND E VALUE AT INTERVALS DURING ACID HYDROLYSIS OF URINE

	Number of Minutes Boiled at pH 1.5							
	0		5 minutes		15 minutes		30 minutes	
Sample No.	NE	E	NE	E	NE	E	NE	E
	μg	μg	μg	μg	μg	μg	μg	μg
335*	2.3		4.9		4.4	....	2.4	....
358	3.0	.09	5.0	.11	3.9	.12	3.0	.06
364	1.5	.02	3.9	.02	3.2	.02	1.9	.01
489	2.6	.43	2.1	.40	3.0	.78	2.1	.74
499	1.0	.02	2.3	.02	1.2	.01	0.9	.01
501	1.4	.35	2.3	.39	2.1	.29	1.9	.27
502	3.3	.07	3.7	.14	2.7	.08	2.3	.11

*Total epinephrine plus norepinephrine: colon assay.

TABLE 2

NE AND E VALUES AFTER β GLUCURONIDASE HYDROLYSIS

Sample	Unhydrolyzed		Beta-Glucuronidase (1%) at pH 6.5 for 2 hrs.	
	NE	E	NE	E
	μg	μg	μg	μg
1*	2.6	...	4.8	....
2	2.9	.33	4.7	.31
3	1.9	.37	3.5	.23
4	3.3	.40	5.5	.32
5	3.2	.03	5.6	.02
6	1.0	.18	3.0	.16
7	0.7	.05	1.7	.04

*Total epinephrine plus norepinephrine: colon assay.

Experiments conducted with β-glucuronidase in a concentration of 0.1 percent showed no increase in the measurable amount of NE.

To test the hypothesis that the conjugated material may be a phenosulfate, Mylase P was used in concentration of 0.1 to 5.0 percent. This was accomplished by the method described by Cohen and Bates (1), which consisted of making various Mylase P concentrations with urine and incubating at a temperature of 50° C. at pH 6.0. Table 3 shows some results when the incubation was carried out for 2 hours. No increase could be observed in either E or NE. When the incubation was carried out for 4 and for 20 hours, the NE and E activities were lost.

In our laboratories the 5-minute acid hydrolysis was adopted as standard procedure

Diurnal Variation

Preliminary experiments were carried out on samples assayed by the rat-colon method which furnished an estimate of the total NE and E. Five samples of day urine were extracted in duplicate and the differences between duplicates were compared with differences observed between the sleep (night) and waking (day) samples of two normal subjects (Table 4). Fair to good agreement was observed in the duplicate samples, but there was much more NE + E in the day samples than in the night samples of two individuals tested (6). In Table 5 are presented data on the NE and E excretion during sleep and waking states on two normal subjects. Night samples of urine were collected during a period from approximately 10:00 p.m. to 6:30 a.m. and day samples were collected from 6:30 a.m to noon. All subjects had breakfast and conducted their usual activities which consisted of laboratory routines. Table 5 contains additional data on six normal subjects consisting of physicians and laboratory personnel who were conducting their usual daily activities (3). Each collected a sample representing the period of sleeping, a second sample from the time of waking to about 10:00 a.m. and a third sample from 10:00 a.m. to the time of retiring at night. There was an increase in the excretion rate of E and NE during the morning and day samples over that observed during sleep. The NE increases were not as large percentagewise as for E values.

Infusion Experiments

P.H., a male chronic schizophrenic (96 Kg.) was infused with NE in dosages of 0.05, 0.10 and 0.20 µg./kg./min. for 30 minutes, in addition to a control saline experiment on a different day. Urine samples were collected before the infusion (9:00-10:00 a.m.), during the infusion (10:00-11:00 a.m.) and after its termination (11:00-12 noon). The same procedure, using E, was carried out on another male chronic schizophrenic subject, J. M. (65 Kg.). Blood pressure and pulse readings were made at 10-minute intervals before the initiation of the infusion and at 1-, 3-, 5-, 10, 20-, 25-, and 30-minute intervals during the infusion. At termination the readings were again made at similar intervals up to 30 minutes, and then every 10 minutes for the next half hour. (4)

Figures 1 and 2 depict the blood pressure and pulse changes after the infusion of E and NE, respectively. Although there was increased tachycardia with increased dosage of E, there was bradycardia after infusion of NE. Though each substance showed a pressor effect, that obtained with NE

TABLE 3

NE AND E VALUES AFTER MYLASE P HYDROLYSIS

(Incubation for Two Hours)

Sample No.	Procedure	NE μg	E μg
496	A. Incubated control	2.2	.31
	B. 0.5% Mylase P	2.6	.29
	C. 2.0% Mylase P	2.8	.30
	D. 5.0% Mylase P	2.0	.21
523	A. Incubated control	2.7	.19
	B. 2.0% Mylase P	2.3	.15
	C. 0.5% Mylase P	2.6	.14
	D. 0.1% Mylase P	2.1	.12

TABLE 4

TOTAL URINARY EPINEPHRINE (E) PLUS NOREPINEPHRINE (NE): COMPARISON OF DUPLICATE DAY SAMPLES VERSUS COMPARISON OF NIGHT AND DAY SAMPLES

Sample No.	Nature of Collection	Total NE + E* (μg./hr)
U 1 A	(D) +	6.4
B		4.4
U 6 A	(D)	1.9
B		1.7
U 7 A	(D)	2.0
B		2.2
U 8 A	(D)	3.0
B		3.4
U 9 A	(D)	1.0
B		0.9
U 3	(N)	0.6
F.E.	(D)	4.4
U 4		
U 10	(N)	1.2
E.L.	(D)	2.8
U 11		

* Colon Assay: estimate of total epinephrine plus norepinephrine

\+ (D) = Day sample (see text) (N) = Night sample

EPINEPHRINE INFUSION

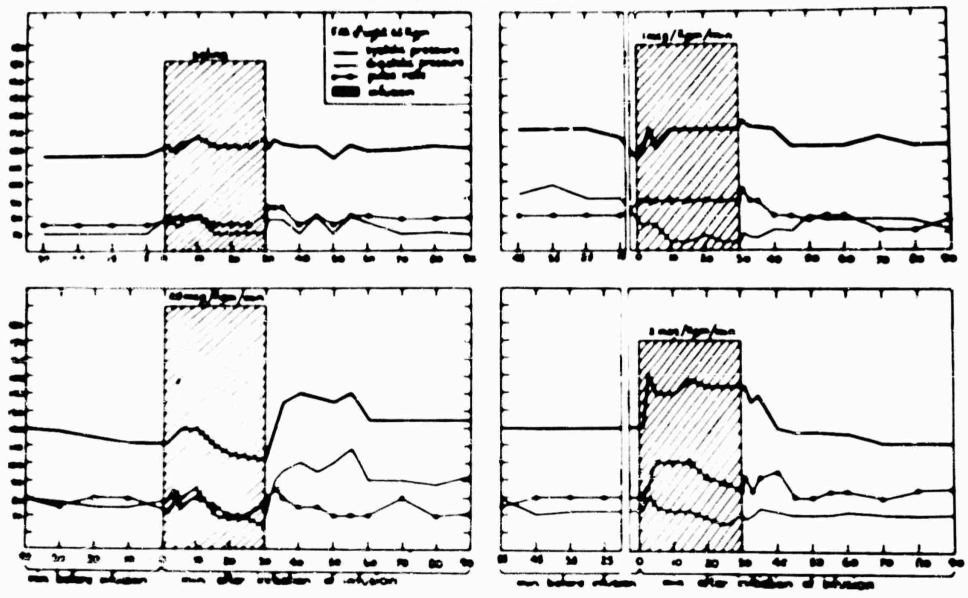

Fig. 1. Blood pressure and pulse measurements in a subject receiving saline, and epinephrine in dosages of .05, .10 and .20 µg./kg./min. for thirty minutes on different days. (Ordinate = blood pressure (mm.Hg) and pulse (beats per min.). (Shaded area = periods of infusion.)

NOREPINEPHRINE INFUSION

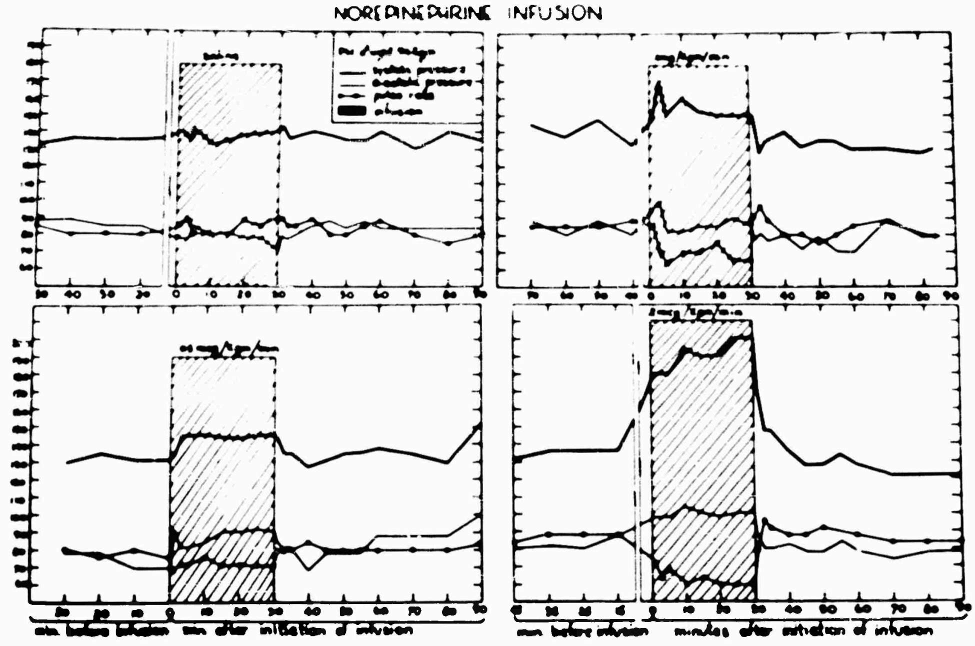

Fig. 2. Blood pressure and pulse measurements in a subject receiving saline, and norepinephrine in dosages of .05, .10 µg./kg./min. for thirty minutes on different days. (Ordinate = blood pressure (mm.Hg) and pulse (beats per min.). (Shaded area = periods of infusion.)

TABLE 5

DIURNAL VARIATION OF NE AND E EXCRETION IN NORMAL SUBJECTS*

		NE µg/hr	E µg/hr
Study A.	Two Subjects		
Sleep:		1.2 ±0.12	0.02 ±0.002
Morning:		2.9 ±0.48	0.40 ±0.10
Study B.	Six Subjects		
Sleep:		1.2 ±0.14	0.02 ±0.01
Morning:		2.3 ±0.49	0.10 ±0.02
Day:		2.4 ±0.60	0.21 ±0.07

* See text for times of collection.

was more pronounced and accompanied by an increase in the diastolic pressure, whereas with E there no change or a *decrease* in the diastolic pressure. The respective changes in the hemodynamics were apparent within one to three minutes after the initiation and termination of the infusion. These results are consistent with those reported in the literature (12). In Table 6 it may be seen that with the infusion of E there was an increase in the E measurable in the urine with increasing dosage, but there was no consistent change in NE excretion. After NE infusion more of the infused amine appeared in the urine than after E infusion (6). When there was a high pre-infusion E excretion, such as before the dosage of 0.10 μg /kg./min. in both subjects, there was a high systolic blood pressure as well as slight increase in pulse rate (Figures 1, 2).

Figure 3 depicts the data of 10 E infusions and 9 NE infusions in doses of 0.05, 0.10 and 0.20 micrograms per kilogram per minute conducted in the manner described above. The data includes the results presented in Table 6. The figure shows the hourly excretion for each dosage rate above its control level. For the NE infusions the relationship of excretion-above-control and dosage seemed to be essentially linear. However, in the case of E infusion, there was a sharp change in the slope at doses above 0.10 μg./kg./min. Although there was two-fold increase in the excretion rate with the doubling of the dose from 0.05 to 0.10 μg./kg./min., there was a sevenfold increase in the excretion rate on subsequent doubling from 0.10 to 0.20 μg./kg./min. These data served in estimating the approximate secretion rates of E and NE in the studies to be reported.

As indicated from these experiments only 0.5 to 2 percent of the infused E could be accounted for in the one-hour post-infusion urine, and 3 to 6 percent of the NE in a similar experiment. This posed the question regarding the fate of the unaccounted material. Dr. Oscar Resnick, of our laboratories, has undertaken the study of the metabolism of E labeled at the beta position with C^{14} as well as with E labeled at the methyl position with C^{14} (Figure 4) (18). As indicated in Figure 5, the excretion of radio-activity is rapidly increased in the urine for the first few hours after the onset of the infusion. In the seven subjects infused with the beta-C^{14} -dl-E-d-bitartrate 91 ± 3 percent of the total radioactivity could be accounted for within 30 hours after the infusion. In the three subjects infused with methyl-C^{14} dl-E- 34 ± 3 percent of the total radioactivity could be accounted for in the urine. The infusion of both types of isotopically labeled E resulted in the increase in the urinary excretion of non-metabolized, biologically active E. This increase was demonstrable only during the first two hours after the onset of the infusion, after which the urinary excretion of biologically active E returned to the control levels. These observations are in agreement with the previous data just shown following the infusion of non-labeled E in human subjects. The increase in biologically active E in these experiments ranged from approximately 1 to 2 percent of the infused E. It should be mentioned that the bioassays of the urine extracts measured biologically active E in the form of its laevo isomers. The radioactivity recovered in the urine, on the other hand, was due to the metabolites derived from both dextro and laevo isomers of the isotopically labeled E and the non-metabolized d-l E.

These results indicated that the metabolites of E are excreted over a 30-hour period. While the E measurable by the bioassay appears in the first few hours (0.5-2 percent of the dose infused), the radioactivity excreted

TABLE 6

EXCRETION OF EPINEPHRINE AND NOREPINEPHRINE IN INFUSION EXPERIMENTS*

Subject J.M. Wt. 65 kg.	Total Dose (ug)	Epinephrine excretion (µg./hr.) Preinfusion	Infusion	Post-Infusion	Norepinephrine excretion (µg/hr.) Preinfusion	Infusion	Post-Infusion
Saline	0	.07	.04	.07	2.4	2.4	2.5
Epinephrine + Infusion							
0.05 µg/kg/min.	95.5	.02	.79	.03	3.0	3.0	1.4
0.10 µg/kg/min.	195.0	.54	1.84	1.20	4.3	1.8	3.4
0.20 µg/kg/min.	390.0	.01	7.04	1.00	1.5	2.5	1.7
Subject P.H. Wt. 96 Kg.							
Saline	0	.10	.15	.20	2.3	5.0	5.5
Norepinephrine + Infusion							
0.05 µg/kg/min.	144.0	.47	.53	.16	2.6	7.8	2.1
0.10 µg/kg/min.	283.0	1.40	.96	1.29	3.5	17.3	8.8
0.20 µg/kg/min.	576.0	.06	none detected	none detected	6.4	22.5	12.4

* Pre-infusion sample of urine was collected from 9:00-10:00 a.m.; the infusion sample, from 10:00-11:00 a.m.; and the post-infusion sample, from 11:00-12:00 noon. The infusion was initiated within a few minutes after 10:00 a.m. and continued for thirty minutes.

+ Adrenaline (Parke, Davis & Co.)

+ 1-Norepinephrine bitartrate, Winthrop-Stearns.

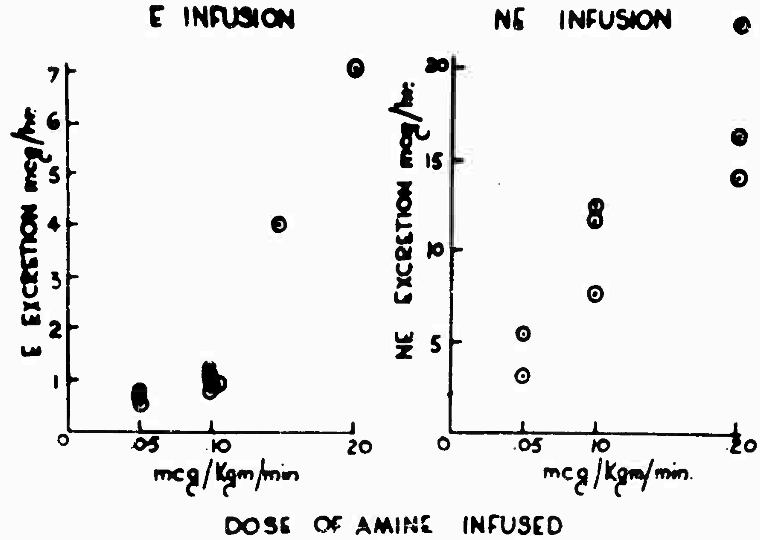

Fig. 3. The excretion of epinephrine (E) and norepinephrine (NE) above control levels after thirty-minute infusion of E and NE in doses of 0.05, 0.10 and 0.20 μg./kg./min. (see text).

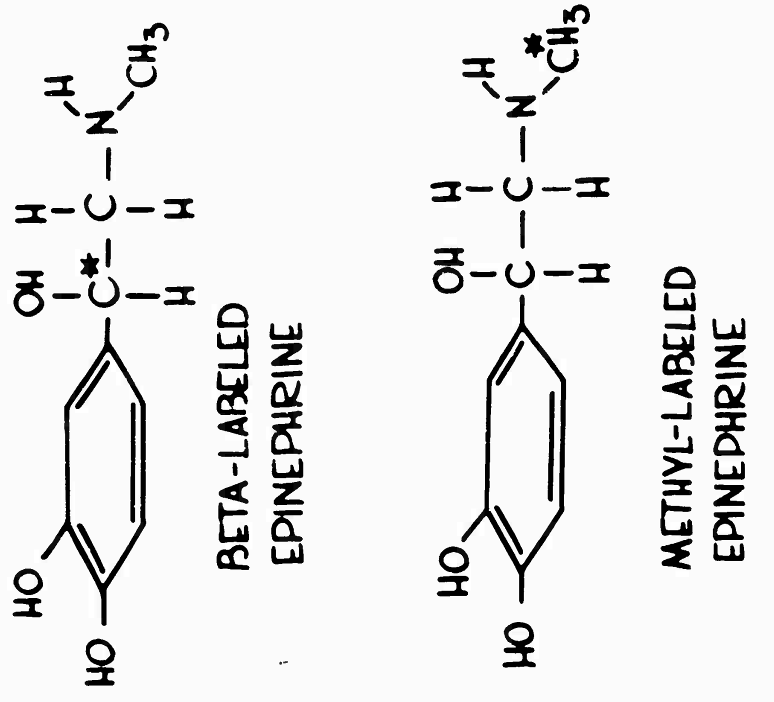

Fig. 4. Isotopic epinephrine used.

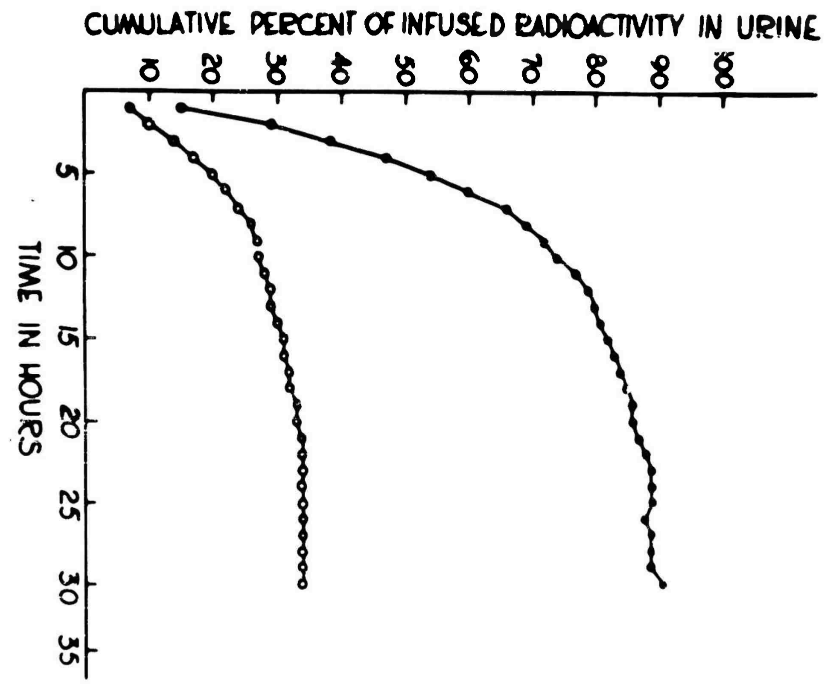

Fig. 5. The average cumulative hourly urinary excretion of total radioactivity. The top line (solid dots) represents the average values for seven infusions with beta-labeled epinephrine. The bottom line (open circles) represents the average values for three infusions with methyl-labeled epinephrine.

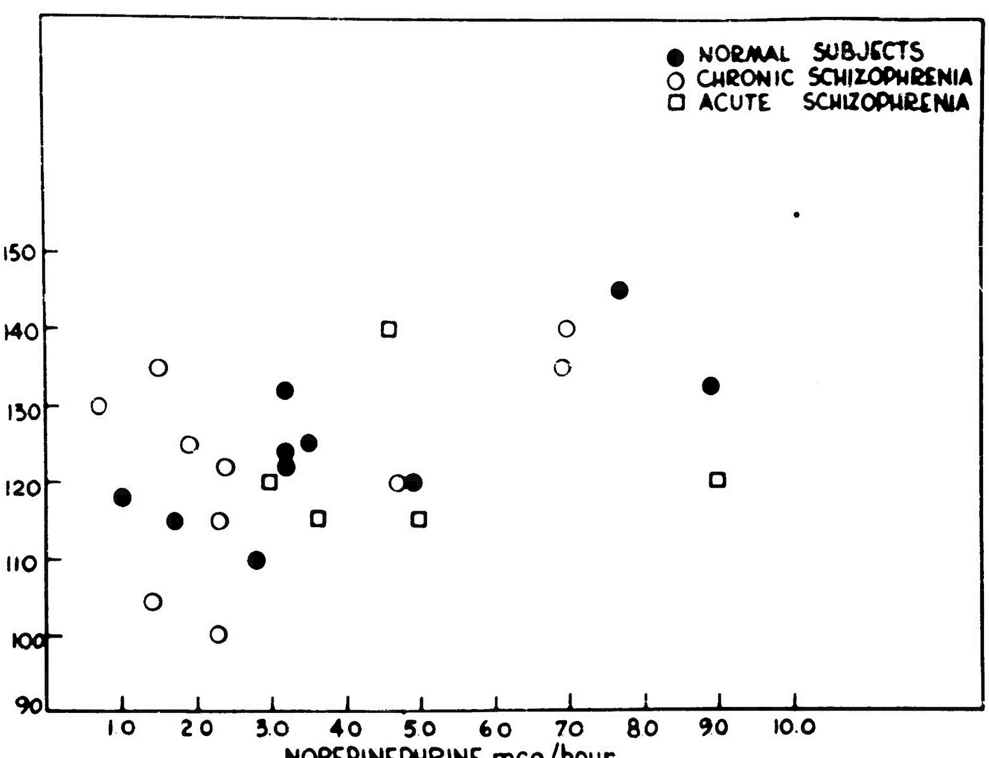

Fig. 6. Relation of the mean resting systolic pressure to norepinephrine excretion rate during the control period.

is 30 to 40 percent (beta C^{14}-E) of the count given during the same period. In addition 65 percent of the metabolized E loses the methyl group during this process. This latter finding seems to support the hypothesis that oxidative deamination does take place in man.

Relation of Resting Systolic Pressure to Norepinephrine Excretion

Figure 6 shows the relationship of the resting systolic blood pressure to the NE excretion (2). The normal subjects show a positive correlation between systolic pressure and NE excretion, with an r = 0.74, which is significant at better than 1 percent level (Table 7). When three groups of subjects (normals, acute, and chronic schizophrenics) are included in the statistic, "r" value is 0.55. Though lower, it is still significant at better than 1 percent level of confidence. In the upper left-hand corner of Figure 6 we observe two chronic schizophrenics who show relatively high systolic pressures and display very low excretion rates. These two subjects were not included in the statistical computations. Both of these subjects showed elevated pulse rates of 80 to 90 per minute. It is also worthy of note that the acute schizophrenics, though few in number, do show marked individual variations. However, in general, it is evident that systolic blood pressure proves to be correlated with NE excretion, with the correlation being highest in normal subjects.

Pursuitmeter

Three-hour Studies: Table 8 shows data on four normal subjects (aged 26 to 34) who operated the Hoagland-Werthessen pursuitmeter (16) (which simulates the operation of the control of a plan) for three hours (6). They had rest periods of five minutes at the end of the first and second hours. The pre-stress control sample represents urine collected during a period approximately between 8:00 a.m. to 1:00 p.m., and the stress represents urine collected during the operation of the pursuitmeter, i.e., from 1:00 p.m. to 4 p.m.

Subject N.G. showed a marked response to stress in E excretion in each of the three experiments. On the other hand, subject S.K. showed little, if any increase in E excretion, but fair increases in NE. Subjects T.H. and F.U. showed, in general, small increases in both E and NE excretions. Though precautions were taken to control the factor of motivation by awarding prize money for the best performance, it is possible that the results were influenced by the relative effort made by each subject in the psychomotor performance. It is of interest that subject N. G. was determined to be the best performer and actually succeeded in being the highest scorer, whereas subject S. K. was indifferent and was the lowest scorer. The number of experiments was too small to serve as a basis for generalization; suffice it to state that consistent increases in E or NE, or both, though varying in amount, were demonstrated in the four subjects tested with this procedure for inducing stress.

Two-hour Studies: Six young men (aged 17 to 19) were subjected to three or four psychomotor-stress tests under hypoxic conditions (10 percent oxygen) for two hours (6). The control urines were collected in the forenoon, as in the three-hour group. The experiments were conducted from 1:00 p.m. to 3:00 p.m., and the subjects did not have any rest during the stress period.

TABLE 7

RELATION OF RESTING BLOOD PRESSURE TO NOREPINEPHRINE EXCRETION (2)

	N	r	P
Normals	10	0.74	< 0.01
All Subjects*	23	0.55	< 0.01

* Two chronic schizophrenics, who gave on repeated testing a high systolic pressure with low epinephrine and norepinephrine excretion values, were omitted.

TABLE 8

EPINEPHRINE (E) AND NOREPINEPHRINE (NE) EXCRETION IN PSYCHOMOTOR STRESS WITHOUT HYPOXIA (HOAGLAND-WERTHESSEN PURSUITMETER)

Subject	Date		E µg/hr.	NE µg/hr.
N.G.	Jan. 26, 1954	(C)*	0.17	4.2
		(S)	1.13	7.6
	Feb. 2, 1954	(C)	0.35	4.2
		(S)	0.93	6.6
	Feb. 9, 1954	(C)	0.48	4.4
		(S)	2.00	3.8
S.K.	Jan. 27, 1954	(C)	0.06	2.7
		(S)	0.07	5.9
	Feb. 3, 1954	(C)	0.08	1.7
		(S)	0.10	2.7
	Feb 8, 1954	(C)	0.15	1.8
		(S)	0.14	3.4
F.U.	Feb. 15, 1954	(C)	0.18	4.0
		(S)	0.23	.. ..
	Feb. 23, 1954	(C)	0.24	1.5
		(S)	0.24	1.7
	Mar. 2, 1954	(C)	0.48	2.0
		(S)	0.68	2.5
T.H.	Feb. 26, 1954	(C)	0.15	2.0
		(S)	0.37	2.6
	Mar. 5, 1954	(C)	0.14	0.9
		(S)	0.16	1.5
	Mar. 12, 1954	(C)	0.09	2.8
		(S)	......	.. ..

* (C) = Control. (S) = Stress (see text).

Under these conditions, considering the subjects as a group, there were significant increases in the output of E during the stress period, compared with the output in control runs. The mean value of the control NE excretions in 18 experiments was 2.3 μg. per hour as compared with 2.7 μg. per hour for the stress samples. The mean value of the control E excretions in 17 experiments was .08 μg. per hour as compared with .18 μg. per hour for the stress samples. The increase in the excretion of E during the stress was significant at 1 percent level. However, it was evident that there were substantial individual differences. Subject P. P. showed a marked increase in E in each of his three runs, whereas subject R. P., his identical twin, showed no increase during the same procedure (Table 9) The individual differences could not be explained on the basis of the scores attained by the subject in this stress procedure.

Psychotic Subjects on Whom Malamud-Sands Rating Scale Records Were Obtained

In ten psychiatric patients a study was made of the relationship between results of Malamud Sands rating-scale tests and the excretions of E and NE (3). This scale (15) rates the patient in 22 categories, and the data are recorded on a check sheet. On the rating scale each item scored is indicated on the left-hand side. A designated base line appears at the center of the rating scale. Going from the base line either to the left or the right, the deviations are observed (Table 10). In the preliminary analysis of the data, motor activity and hostility reactions were abstracted and a composite score including these two items was computed In figure 7 is shown the relationship of this score to NE excretions; those with passive, self-effacing emotional display had normal levels of NE. In Figure 7 when a line appears through the circles, it indicates that these subjects also had a high excretion of E The subject indicated by an asterisk had normal NE excretion, but the excretion of E was 2.75 μg. per hour, which is extremely high. This subject showed periodic bursts of excitement with expressions of fear and guilt.

Neuropsychiatric Patients during Staff Interviews

The conditions of the interview were in marked contrast to those encountered by the athletes or the patients on the psychiatric ward. The patient sits across from the psychiatrist doing the interviewing in the presence of some 20 members of the hospital medical staff. The setting is serious, and to the patient it is very important because, on the basis of his performance, decisions are made by the staff which affect his immediate future.

Eleven subjects were studied, on eight of whom control urine samples were obtained (3). The interview took place on Thursday mornings, and the control sample was obtained at the same time on the next day — Friday. The results are listed in Table 11. There were no changes in the NE excretion when the interview day was compared with the control. However, in every subject on whom a control was obtained there was an elevated excretion of E during the interview. As might be expected, there was marked individual variation in this increase. The subjects in general were self-effacing and on their best behaviouh with no aggressive or active display.

TABLE 9

EPINEPHRINE (E) AND NOREPINEPHRINE (NE) EXCRETION IN PURSUITMETER STRESS WITH HYPOXIA

Subject	Age	Date		E µg/hr.	NE µg/hr.
P.P	17	July 19, 1954	(C)*	0.10	1.4
			(S)	0.42	1.6
		Aug. 3, 1954	(C)	0.03	3.2
			(S)	0.26	5.2
		Aug. 31, 1954	(C)	0.04	2.0
			(S)	0.35	3.4
R.P.	17	July 15, 1954	(C)	0.14	1.5
			(S)	0.16	1.5
		Aug. 6, 1954	(C)	0.09	3.0
			(S)	0.05	1.6
		Aug. 27, 1954	(C)	0.16	2.2
			(S)	0.17	1.5

* (C) = Control. (S) = Stress.

TABLE 10

PORTION OF THE PSYCHIATRIC RATING SCALE OF MALAMUD AND SANDS

FUNCTION	6	5	4	3	2	1	BASE	LINE	1	2	3	4	5	6
APPEARANCE	Bizarre		Decorative		Over-Meticulous		NEAT	CARE-LESS	Slovenly	Untidy	Incontinent		Smearing	
MOTOR ACTIVITY	Excited		Agitated		Restless		ACTIVE	QUIET	Under-Active		Retarded		Stuperous	
MIMETIC EXPRESSION	Incongruous		Dramatizing		Exaggerated		ANIMATED	RE-STRAINED	Stiff	Waxy-Flexibility			Mask-like	
RESPON-SIVITY	Anaklitic		Suggestible		Dependent		FLEXIBLE	RIGID	Stubborn		Resistive		Negativistic	
HOSTILITY REACTIONS	Destructive		Combative		Belligerent		AGGRES-SIVE	SELF-EFFACING	Self-Deprecating		Self-Mutilating		Suicidal	

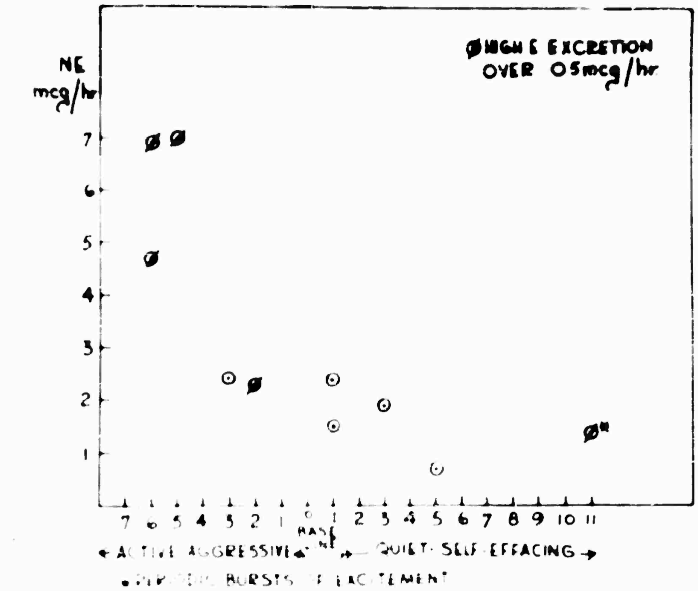

Fig. 7. The relation of norepinephrine excretion to emotional state of neuropsychiatric patients. (The abscissa depicts the composite score for the functions of motor activity and hostility reactions from the Malamud-Sands rating scale, and the ordinate represents the excretion of norepinephrine in μg. per hour during the observation period.)

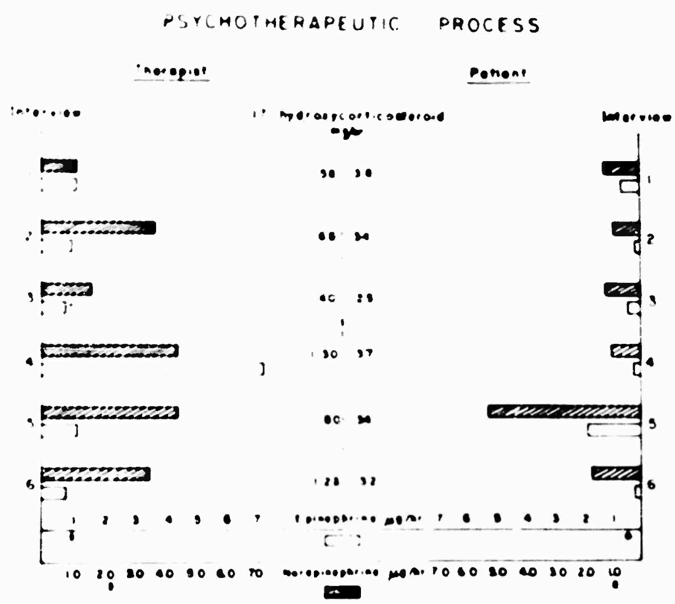

Fig. 8. Data on therapist and patient during 6 psychotherapeutic interviews. "indicates normal values for E and NE for patients. + represents normal values for therapist for same time of day when not engaged in psychotherapeutic process. Open bar indicates E excretion μg./hr.; hatched bar, NE excretion μg./hr.; 17-hydroxycorticosteroids of same samples given in center of figure as mgm/hr.

TABLE 11

STAFF CONFERENCE INTERVIEW OF NEUROPSYCHIATRIC PATIENTS

	N	NE µg/hr.	E µg/hr.
Interview	11	2.6	.50
		±.4	±.14
Control	8	2.3	.27
		±.2	±.12
Difference		NS	P = less than .001

Examples of the variability observed on two patients are presented below.

Patient J.C. —"The patient is rather sloppy in his posture and attire. Responses are brief, to the point with little elaboration, and occasionally evasive. The patient has a shifting amnesia for recent events and is unable to give a coherent description of what happened prior to admission and since. He questions and guesses the month as December. Although there is a history of intense alcoholism and some evidence that the patient hallucinated during the first part of his hospitalization, he denies any such experiences. — There is a history of recent seizures, CSF total protein elevated and EEG showed slowing in anterior leads."

Diagnosis: 1. Acute Brain Syndrome of Unknown Etiology

2. Acute Alcoholic Intoxication

During the interview J. C. was calm, unperturbed by the event and showed no overt evidence of anxiety.

	NE µg./hr.	E µg./hr.
Interview	2.5	0.19
Control	3.0	0.05

Patient W. D. — "The patient is alert, attentive; he is fidgety, uneasy, and tense during the first part of the interview, expressing anxiety at the interview situation although this seems to largely disappear at the end of the interview. He is ingratiating, expressing himself well, with a vocabulary indicating good intelligence. There is no evidence of delusions, hallucinations or formal disturbance in thought. His affect seems shallow and there seems to be little evidence of real remorse or feelings of guilt. His judgment is inadequate and he shows a long-standing personality pattern of superficial relationships with people and a narcissistic immature attitude."

Diagnosis: Dissocialization Reaction.

During the interview W. D. showed evidence of tenseness and anxiety. He was perturbed by the interview situation and stated his concern and anxiety over the interview situation.

	NE µg./hr.	E µg./hr.
Interview	1.1	1.60
Control	1.8	0.15

Psychotherapeutic Process

In the course of psychotherapeutic treatment, samples were obtained from both therapist and patient. The therapeutic interviews took place between 8:00 a.m. and 9:00 a.m. Samples were obtained before and after each therapeutic session as well as on control days during the same hours when neither subject was involved in a psychotherapeutic interview. Six psychotherapeutic sessions and six control days were studied. Urine samples obtained were analyzed for NE, E and 17-OHCS (20). Figure 8 contains the data on both therapist and the patient, obtained during the therapy session. Along the abscissa are indicated the control values for both the therapist and the patient. During the first interview we observe that both patient and therapist showed normal values during the psychotherapeutic session as compared to their control. In the second session a slight elevation is observed in the NE and 17-OHCS excretion for the therapist, with the patient still within normal limits for these determinations. In the third session the results indicate that all values are within normal limits. In the fourth psychotherapeutic interview, the samples indicated a twofold increase in the 17-OHCS excretion with marked elevations for both E and NE for the therapist. The patient still showed normal values. In the fifth psychotherapeutic session, we observe elevated 17-OHCS values for the therapist, accompanied by high values in NE, but E values returned to normal. However, we now observe the patient showing a marked increase in NE excretion with considerable elevation in E excretion, with no increase in 17-OHCS. In the sixth interview we note again a highly elevated 17-OHCS excretion for the therapist, with a moderately high NE value and normal E excretion. The patient's value shows an elevated NE, but E was back to normal.

Information obtained from the therapist indicated that in session number four the therapist was severely criticized by the patient and the interview got "out of hand." The therapist was aware of his predicament subjectively and did admit unpleasant emotional experience. In the fifth session, during the course of the psychotherapeutic interview, the patient cried, showing considerable emotional expression. The therapist was quite concerned about the turn of events which had now taken an unexpected course with regard to the therapy. This aspect is also shown in the sixth session where the therapist again shows high values in 17-OHCS and an elevated NE excretion.

These data indicate that there is a possibility to study, by means of these measurements, the emotional exchanges between the therapist and the patient during a psychotherapeutic process. From the physiological point of view it may also be noted that excretion of these substances during such an interview apparently reach levels which are identified with stressful tasks such as operation of the pursuitmeter or participation in athletics. These results again show that NE excretion under certain circumstances increases without an elevation in E, which further emphasized the fact that these hormones may be differently secreted, possibly depending on the nature of the emotional stress and the accompanying sympathico-adrenal responses.

SUMMARY

Urinary NE titer was shown to increase with acid hydrolysis and incubation with beta glucuronidase while E appeared to be mostly in free

form. Experiments with Mylase P as a source of phenolsulfatase gave negative results for both catechol amines.

Infusion experiments indicated that only 0.5 to 2.0 percent of the infused dose of E and 3.0 to 6.0 percent of NE was accountable in urine by bioassay. Studies with isotopic E (C^{14} labeled at the beta and methyl position) supported the view that oxidative deamination was a major metabolic pathway.

Variations in E and NE excretion were demonstrated in various emotional states. The results support the hypothesis that NE excretion is increased when there is an active aggressive emotional display and E excretion is elevated in cases of tense, anxious, but passive display.

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SECRETION OF ADRENALIN-NORADRENALIN

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We have approached the problem of measuring stress from the viewpoint of the adrenalin-noradrenalin in the blood, using the method of Wildnow, Herby, and Bone, developed in England about three years ago, slightly modified. This is a fluorometric method applied after the separation of the catacolamines on the chromatographic column.

Our work at Walter Reed Hospital consisted of studying the response of rats that had been subjected to tumbling trauma. We found that under this type of stress there was a very marked change in both catacolamines, both rising very markedly, and, pecularly enough, sustained for long periods of time. Neither of the values returned to normal before six hours.

Controlled studies on human subjects at Walter Reed showed that there is no measurable level of adrenalin in the plasma. The mean concentration of noradrenalin in the plasma runs in the neighborhood of 2 to 3 mcg per liter. No work was done on stress in humans at that time, although work is now under way studying patients being subjected to electro-shock, and I might mention at this time that there appears to be a very marked relationship between the noradrenalin concentration that one sees after the electro-shock and the type of sedation given.

Phenobarbital, which does not completely destroy the muscular activity following electro-shock, completely blocks the secretion of noradrenalin following the shock. This is something that is currently being investigated.

At Natick we are in the process of studying the changes in the concentration of the catacolamines under the various environmental and work conditions. The preliminary data indicate a very marked increase of noradrenalin during short, exhaustive work with the adrenalin secretion increasing only in those men whom we evaluated as being quite upset about the whole test.

PSYCHOMOTOR FUNCTIONS

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When we start talking about psychomotor performance, we start with (1, 8) not one but with two kinds of quite severe handicaps (1). First, we start with a multiplicity of real-life operations. Secondly, we encounter in the laboratory a very high specificity of motor functions. For example, in the intellective area, the concept of intelligence quotient as a measure indicating a general level on which an individual can function intellectually is useful. On the psychomotor level there simply is not anything approximating a "psychomotor quotient." In other words, you can have an excellent performance in driving a truck, with a very good accident record and very good efficiency in terms of miles driven per gallon of gas, but at the same time you can be a very miserable violin player. This demonstrates the specificity of motor performances. So, where do we stand? From the outset we are forced to choose between the one or the other approach.

We may decide to use the so-called miniature work situations (3). These are simplified replicas of actual job situations. In the past, a variety of actual life performances have been modified for laboratory use, but quite clearly the simulation of operating an airplane has been used most heavily. In experimental studies on stress we can use only one or, at the most, a very small number of these miniature work situations as measures of performance capacity. Here we try to duplicate, in a simplified manner, some specific performance or class of work operations.

On the other hand, we can use the more abstract tests of biological components of performance capacity (2, 4). It is at this point that I would have welcomed particularly the presence of Dr. E. A. Fleishman who has been much concerned with these problems. The question of selection of the tests is very crucial. It will depend on several factors, two most importantly, perhaps three.

First, interrelation between different facets of motor performance. To work most economically, we want to use a battery in which each test contributes something new — adds a maximum of information. In other words, we want tests which show, technically speaking, low intercorrelations. At the same time we want to measure some aspects of performance capacity that have a broader applicability, that have validity in terms of real-life situations.

Secondly, and in stresses perhaps even more importantly, we are concerned with the sensitivity of tests to different situations. I shall say something more about this later, so now I will just bring up the idea.

Perhaps in parentheses I might say that there is another aspect which is crucial in the practical application, and that is the length of time necessary to arrive at a stable training practice plateau (4).

So we have intercorrelations between the tests, their sensitivity to the stresses, and the length of time necessary for practice during the control

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period. But how many tests should be used? We have two types of situations. In fundamental studies, such as studies on the effects of prolonged caloric deficiency (5), or in any situation in which we are interested in the over-all biological impact of the stress situation on man, we should include as much as possible the whole spectrum of the components of performance capacity.

On the other hand, in applied studies — for example, when we are comparing the relative effects of maintaining individuals on two levels of a nutrient — only those functions that have been proved or that can be expected to be sensitive to this stress should be included. Here we are concerned with the differential effect.

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SCIENTIFIC MOTION ANALYSIS APPLIED TO ASSESSMENT OF HUMAN PERFORMANCE

by

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There are many ways of assessing human performance capacity and many points of view regarding this problem. Some physiologists and psychologists search for and ideal single index of performance in the hope that all work capacity can be reduced to some universal measure of energy exchange. Others, especially psychologists, have attempted to devise tests of performance which place emphasis upon prediction of learning ability and skill. Industrial engineers have attempted to set standards of work capacity in terms of either negotiated agreements or unilateral decisions based upon time-study techniques.

We have approached this problem of assessing performance capacity in terms of a functional point of view. We believe that no single measure of performance can have universal application to the varied activities of the human system. On the other hand, performance has some consistency, and there are principles enabling us to understand this consistency in behavior. Such varied aspects of human performance as rate of movement in walking, manual accuracy and skill, muscular strength, speech and verbal behavior must be understood and measured in terms of the intrinsic properties which define their functional significance in particular tasks. Furthermore, various levels of vital interaction must be recognized in order to gain any real knowledge of motor capacity. Thus the levels of human performance must be studied, not in terms of some one measure of activity alone, but in terms of the interplay between internal environment, physiological states, and external behavior in relation to the demands of the physical and social environment. The ambiguous distinctions commonly made between mental and physical work have no meaning in a scientific approach to problems of measurement of performance.

A second point may be made about methodology in this field. Psychologically, we can think of human performance primarily in terms of the properties, components, and dimensions of human motion. The evolution of the higher organisms, especially that of the human individual, has been marked by a very great differentiation in adaptive capacity, psychologically and physiologically. Internally, the human machine is organized in great depth to withstand extreme stress and to adjust to different circumstances. Externally, differentiated performances show marked specificity. The common features in these varied performances are functionally differentiated movements within larger patterns of organized motions. All motions involve functional components of posture, of transport of the body in space, and of manipulative contact movements which are articulated with reference to the space dimensions of objects and surfaces. Scientific motion analysis of these distinctive components of motion is fundamental to all aspects of performance study.

We think of all human motions as organized in terms of (a) functionally

defined component movements, (b) psychological and physiological dimensions, and (c) quantitative movement properties of force, rate, frequency, duration, reaction time, accuracy, and relative efficiency (16). The psychological dimensions which must be considered in assessing level of performance in any task are development, learning, motivation, and various perceptual dimensions. As we stated above, all motions consist of at least three functionally distinct types of component movements — postural or supportive movements, travel or transportive movements, and manipulative or contact movements. Travel movements serve the generalized function of transporting the body or parts of the body in space, and of supplying the force essential for such transport, whereas manipulative movements have the generalized function of articulating the motion in order to fit it precisely to the space and time characteristics of stimuli, objects, and surfaces in the environment. Our electronic methods of motion analysis (20) are designed specifically to measure the characteristics of manipulative and travel components of a great variety of human motions, including tool and machine operations.

Electronic Methods of Motion Study

We have applied electronic methods of motion study to the analysis of such varied forms of human performance as gait, stairclimbing, handwriting, assembly skill, panel-control operations, and different patterns of unimanual and bimanual dexterity. The principles of this method of motion analysis are diagrammed in Figure 1 (20). A subthreshold electric current is passed through the operator's body, so that each time he touches some surface, object, or control, he automatically closes a relay that activates a precision clock (19). In addition, the circuit also contains a flip-flop circuit so that when the subject moves toward a second object or control, breaking the first contact, the contact time clock is stopped and a travel clock is started. This travel movement clock stops when the second contact is made. Finally, we add a stop circuit to the system, which is activated by a contact at the end of a motion pattern. When this contact is made the whole timing system is stopped, and a precise summation obtained of the duration of the travel and manipulative movements involved in the motion.

Figure 2 illustrates the application of these electronic methods to the measurement of panel-control motions (10, 22, 23). This set-up involves a two-channel analyzer, one channel of which records the time of the manipulative movements and the other travel movements. This motion analyzer has turned out to be especially valuable in measuring the effects upon motions of sustained stress, such as starvation, thirst, and sleep loss.

Figure 3 diagrams the application of a two-channel electronic motion analyzer to the measurement of handwriting performance (17). In this technique the subject uses a metallic pencil (filled with electrographic lead) and writes on Teledeltos electric recording paper. The duration of the contact movements is measured separately from that of the travel movements. When the subject comes to the edge of the paper, he touches the stop plate and automatically terminates the timing process. We are especially interested in using the elctronic Handwriting Analyzer for assessing age changes in the component movements of motion, because the handwriting task is learned early in life and practiced by most people throughout the course of life. Accordingly, these motions provide a means of assessing age changes in a performance practiced regularly by all subjects.

We also employ the two-channel electronic motion analyzer to analyze

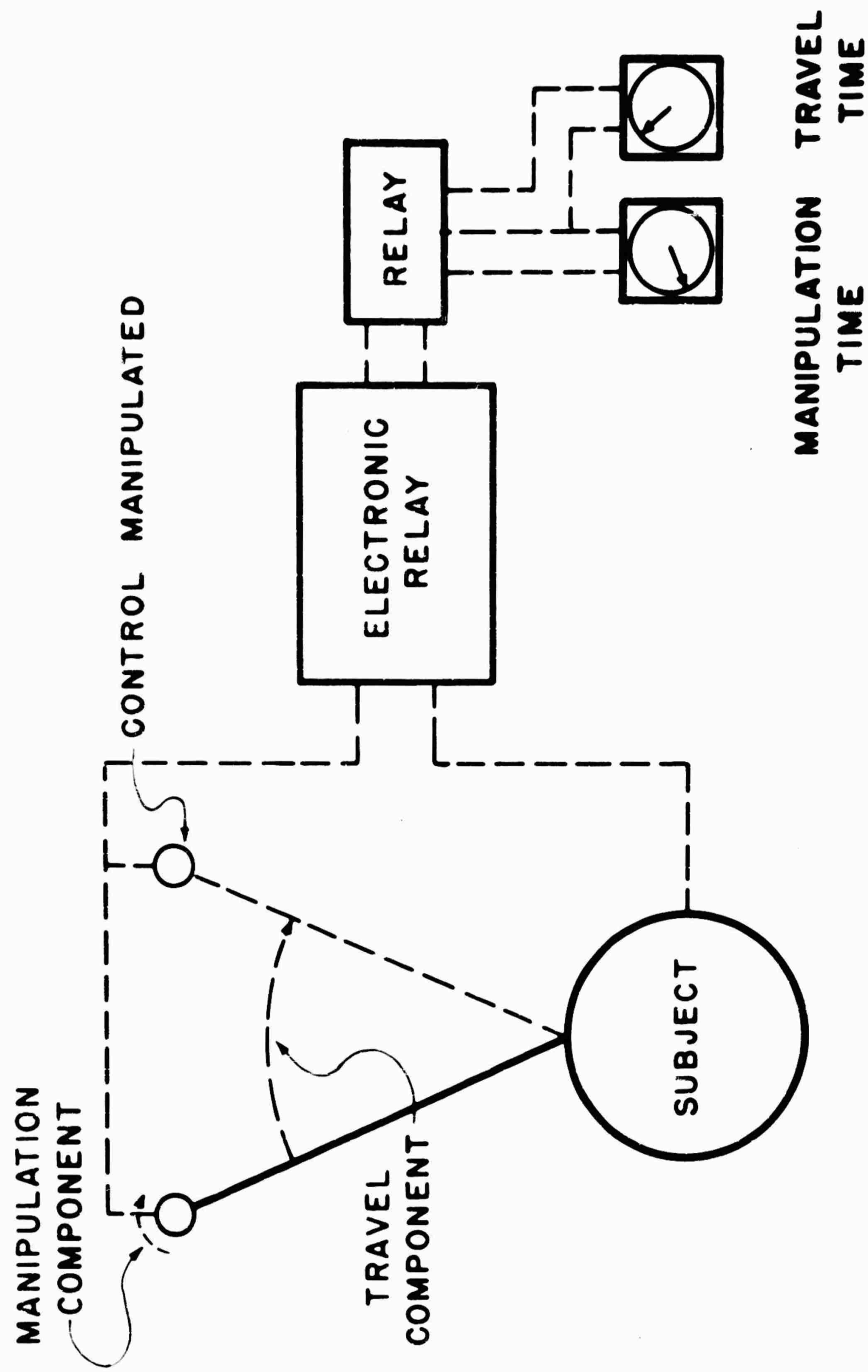

Fig. 1. Diagram of the circuit relations involved in the electronic method of motion analysis.

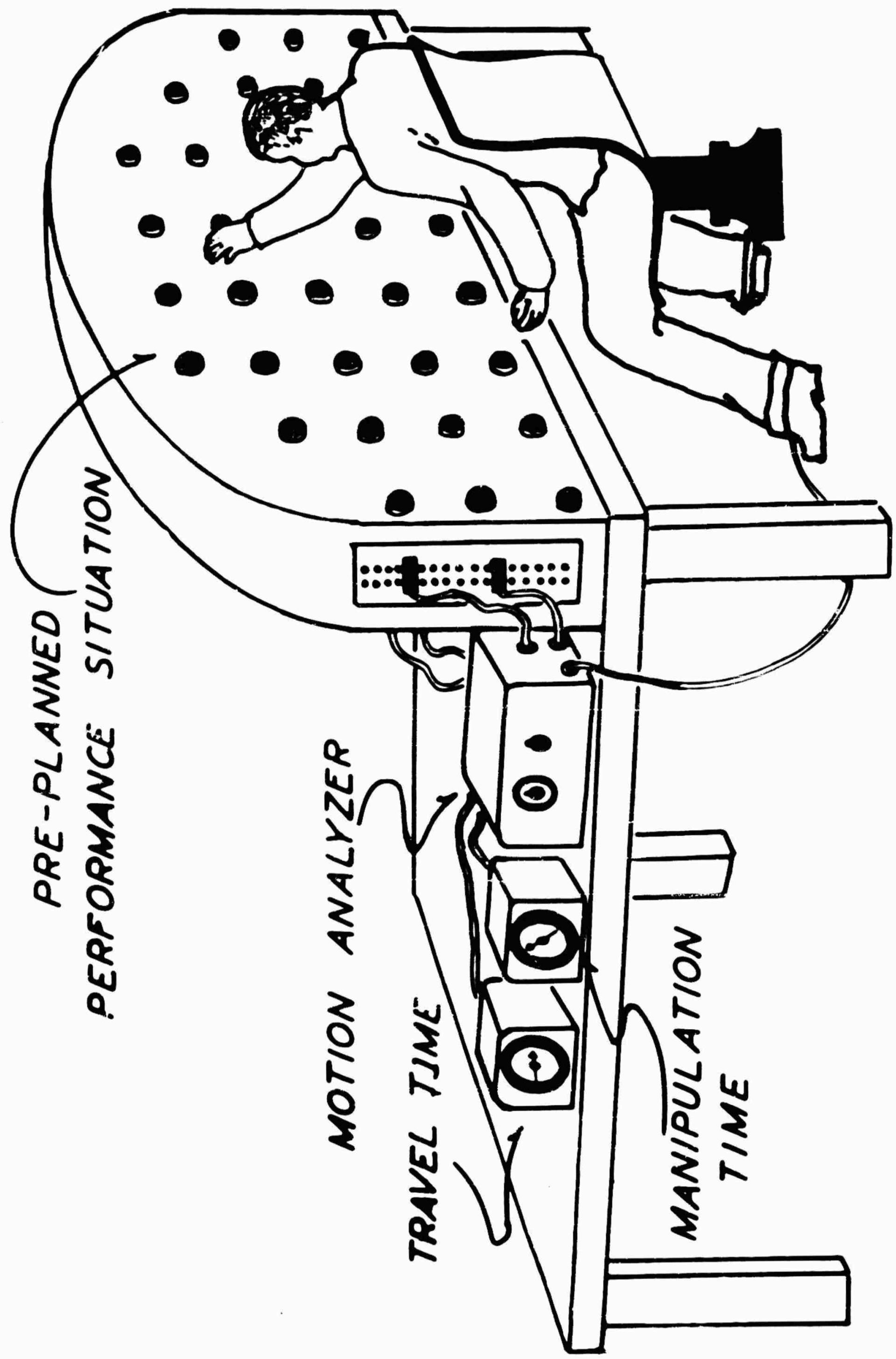

Fig. 2. Diagram of a two-channel electronic motion analyzer applied to the measurement of the manipulative and travel movements of a panel-control operation.

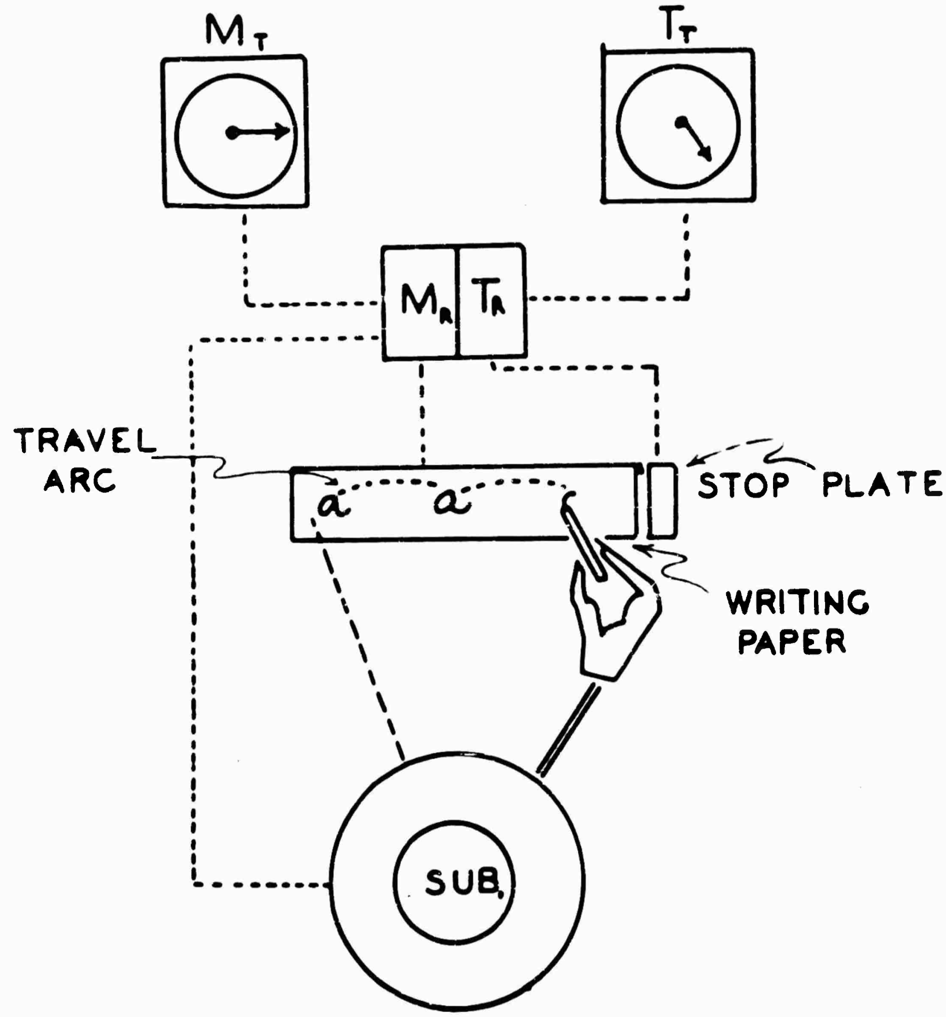

Fig. 3. Diagram of the principle of the electronic handwriting motion analyzer.

human gait. Figure 4 pictures the arrangement of the apparatus. The subject walks on two heavy brass runways, which are separately connected to a precision gait analyzer. Other plates at the ends of each runway serve as stop contacts when the subject reaches the end of the runway. The contact and stepping motions of the two feet are recorded separately. When one foot touches the brass plate in the step, this contact time is automatically recorded, and as the foot is lifted in the step, the travel or step time is recorded. Connections are made so that the simultaneous contact or bipedal contact time can be timed separately from the bipedal step time.

These electronic methods of motion analysis can also be employed to measure complex performances involving assembly and machine skills (12, 13). Figure 5 illustrates the application to assembly skill. Figure 5a shows the set-up of a work bin and an assembly plate (shown to the far right) along with a 4-channel motion analyzer. The television camera and monitor are being employed to study effects of perceptual stress and of displacement and distortion of the visual field upon work performance. The movements recorded in this case are the four basic parts of the assembly cycle-grasp, carry, place, and return. In this cycle (Fig. 5b), pins are removed from the small bin and placed in the assembly plate. The four clocks to the left automatically record and sum the durations of the separate movements. The television camera is mounted directly above the work place and may be moved about for assessment of effects of displacement of the visual field.

Characteristics of Motion in Performance

The methods of motion study just described represent a new operational approach to the theory of motions and the dimensions of performance (16). They constitute a systematic way of measuring organized motions in relation to their space and time structure, and provide a firmer foundation for experimentally oriented motion analysis.

Motion study methods have not been applied heretofore to performance assessment because the applied methods available for such purpose — the stop watch and the fast motion picture — are neither accurate nor economical enough for such application. In contrast, the electronic methods just described have the necessary precision and economy required for such an application. For example, millions of feet of motion picture film would be needed to time the motions which we measure routinely in a study covering some 50 subjects, each of whom performs a task requiring 20 minutes of practice per day for 10 days.

Motion analysis methods are essential for a quantitative assessment of the interactions and coordinations of the distinctive component movements in performance, as well as for adequate measurement of the effects of variations in motivation, stress, learning, perception, and the like. Let us examine first the problems of measuring movement interaction and coordination in performance.

Assessment of Movement Organization

We consider this problem a primary one in the psychomotor field. Theoretically, the measurement of movement interaction and coordination enables us to evaluate general behavior theories as they are applied to performance. Practically, these measures give us indices of certain properties of performance which may shift and change with conditions in motivation

Fig. 4. The arrangement of the recording runway and recording components of an electronic gait analyzer.

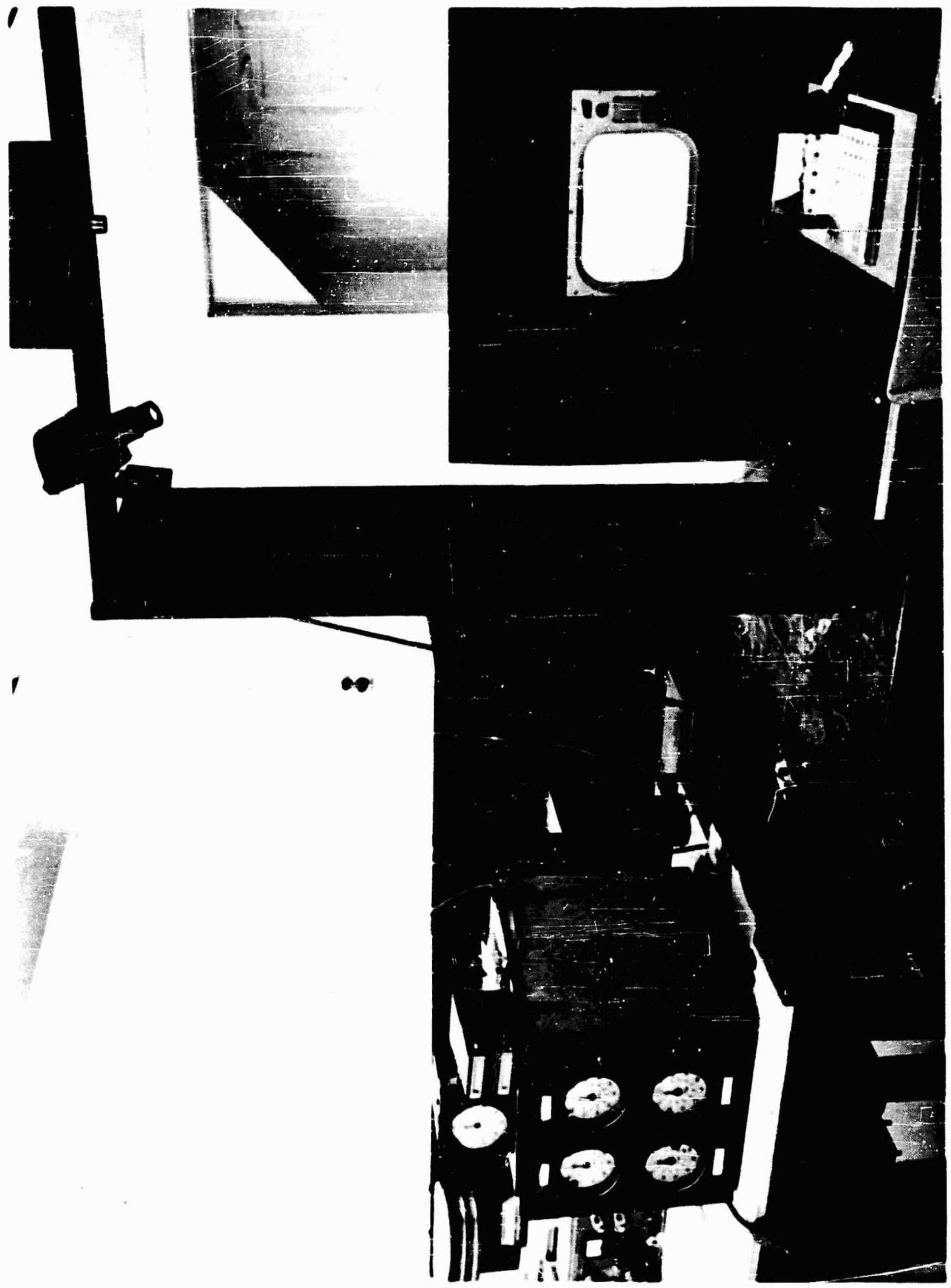

Fig. 5a. Arrangement of recording and control apparatus for analysis of assembly performance in substitute televised visual fields. The locus of the television camera above the assembly place and the timing units of the four-channel analyzer are shown in Fig. 5-A. The photograph in Fig. 5-B shows the detail of the assembly place in relation to the television monitor. In actual experiments the operator can observe the actions of his hands only by means of the television monitor.

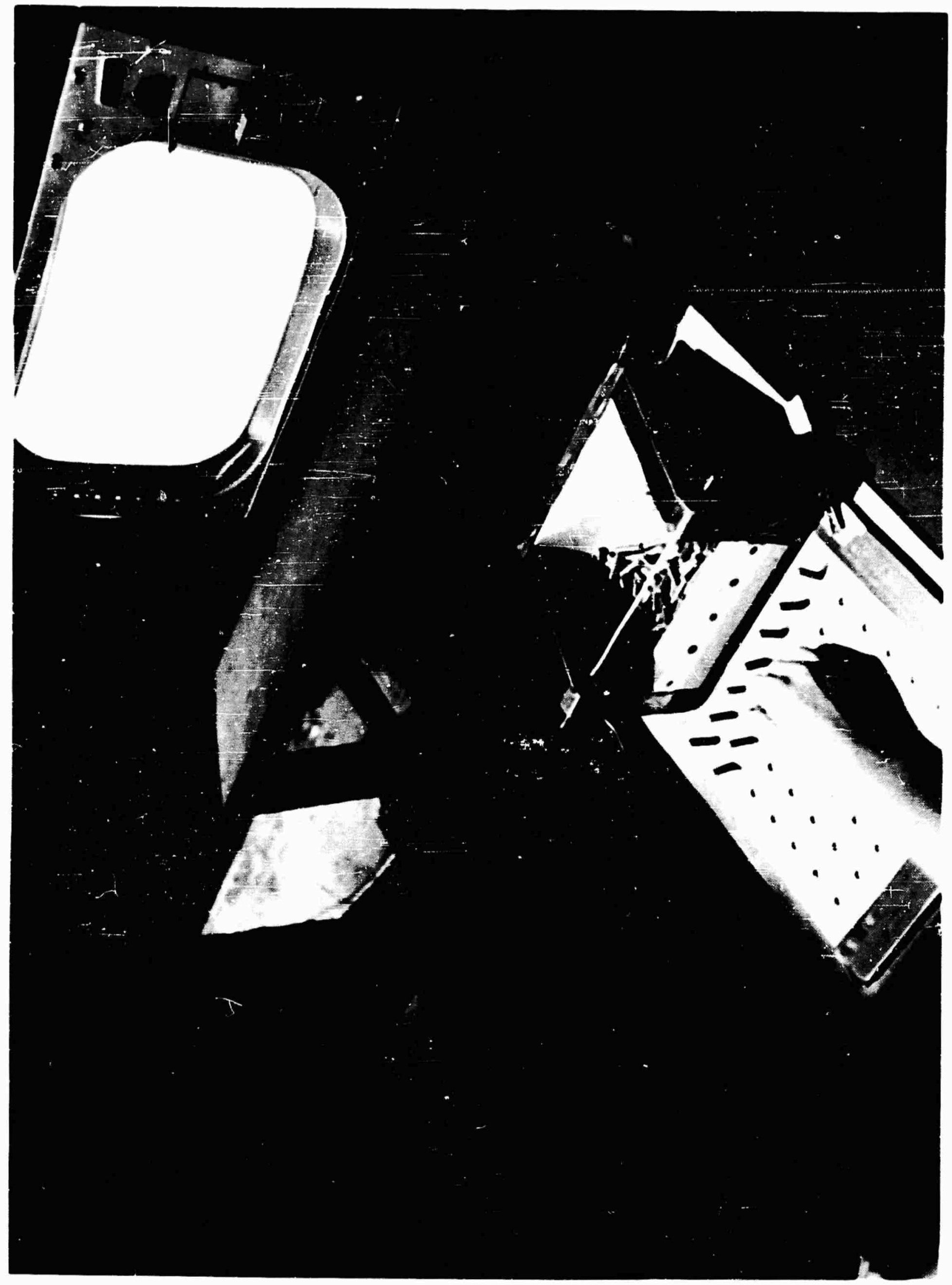

Fig. 5b. Arrangement of recording and control apparatus for analysis of assembly performance in substitute televised visual fields. The locus of the television camera above the assembly place and the timing units of the four-channel analyzer are shown in Fig. 5-A. The photograph in Fig. 5-B shows the detail of the assembly place in relation to the television monitor. In actual experiments the operator can observe the actions of his hands only by means of the television monitor.

and fatigue independently of the absolute duration or precision of performance.

The apparatus diagrammed in Figure 6 illustrates how the interactions of movements in organized motions are measured directly (5). The manipulation boards on the work panel can be replaced quickly by boards containing other types of manipulative devices. Eight such devices were used. The variation in duration of a travel movement of constant length (60 cm) was measured in order to get a direct measure of the interaction between the various types of manipulation movements and the travel movements. The results show that marked interaction effects occur between the component travel and manipulative movements in motion. Thus, the duration of the travel movement in this task increased as much as 52 percent with different types of manipulation. The travel movement of a dial setting manipulation was found to be 52 percent longer in duration than the same movement associated with the turning of the switches shown in Figure 6.

TABLE 1

CHARACTERISTICS OF INDIVIDUAL DIFFERENCES IN WRITING LETTERS OF THE ALPHABET

	Manipulation		Travel		M/T	M vs. T
Subject	Mean	σ	Mean	σ	Ratio	Correlation
1	.640	.191	.269	.035	2.38	+.12
2	.566	.154	.280	.077	2.02	.00
3	.413	.105	.243	.070	1.70	+.06
4	.462	.136	.209	.050	2.22	—.31*
5	.478	.120	.279	.098	1.71	+.57**
6	.533	.121	.315	.066	1.75	+.13
7	.581	.119	.230	.056	2.52	—.21
8	.423	.091	.208	.045	2.03	—.09
9	.641	.149	.263	.053	2.43	—.07
10	.698	.107	.212	.038	3.29	+.11

* Significant at the 5% level

** Significant at the 1% level

Measuring the movement components in motion enables us to give quantitative expression to aspects of rhythm, tempo, and coordination in performance (17). Table 1 illustrates two such measures of movement organization in handwriting. The ten subjects wrote 35 single letters and numbers. Different characters were written in different trials. The contact time and travel time in writing these single letters or numbers repeatedly were measured separately. The means and standard deviations for these two movement durations for each subject are given in the table.

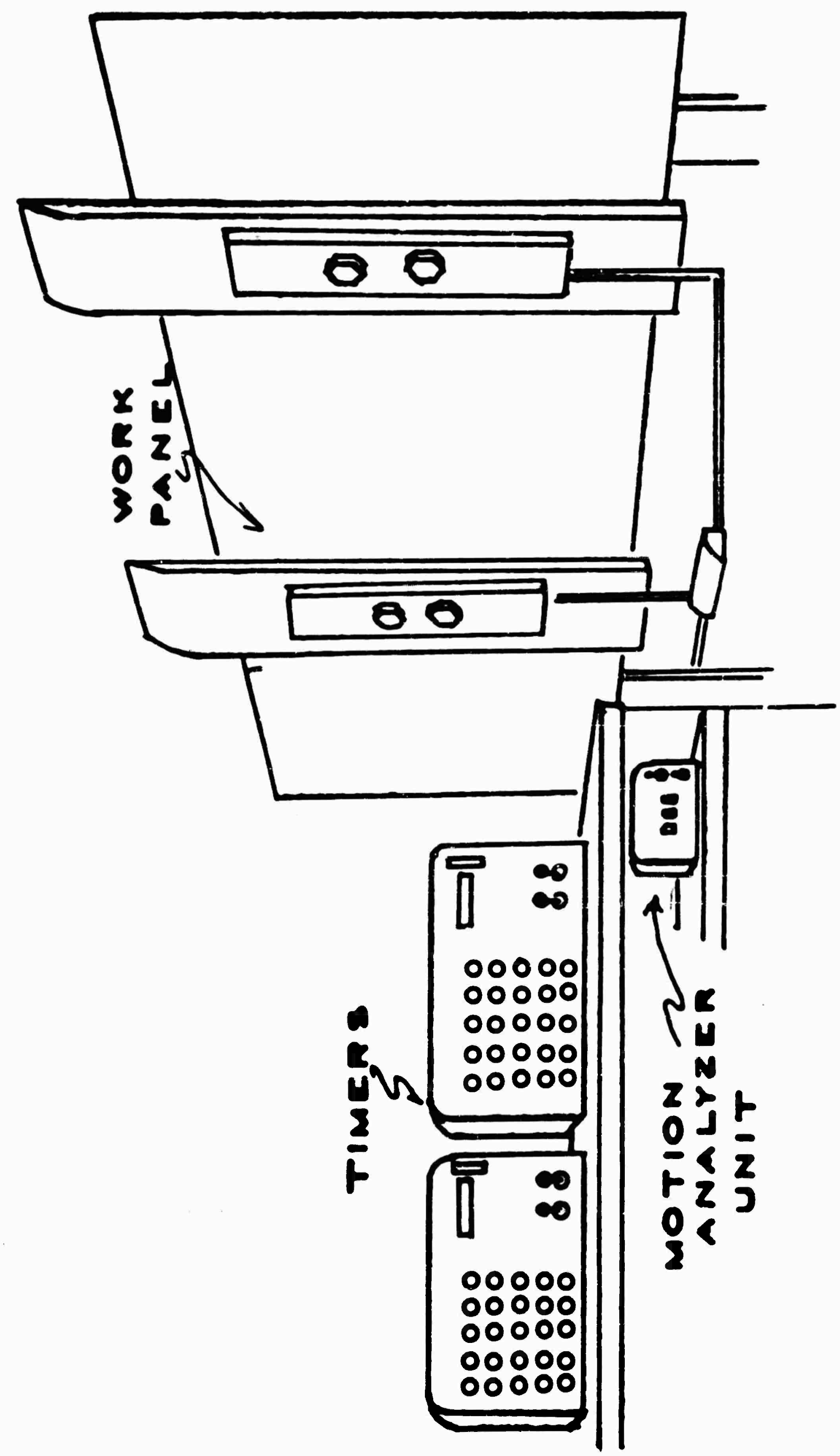

Fig. 6. Diagram of a work panel for direct measurement of the interaction effects between travel and manipulative movements upon the duration of the travel movement.

In order to compute a measure of tempo in writing for each subject, the manipulation time of each character was divided by its corresponding travel time to get the manipulation travel ratio. It is a relative measure that may remain constant while the absolute values of the manipulation and contact time vary.

The standard deviation of the manipulation and travel time of specific pairs of movements gives us a measure of rhythm or the magnitude of variation in tempo. We have computed such measures but have not studied them extensively since we do not have as yet an economical way of recording and processing data on the duration of individual movements.

In order to get a measure of coordination in movement, we correlate the time of manipulation for different tasks (such as writing the 35 different letters and numbers) with the corresponding paired travel times in these tasks. The manipulation vs. travel correlations shown in Table 1 are examples of this special measure of coordination. It will be noted that these correlation values vary greatly with different subjects. Some are significantly positive, some do not exceed a chance level, while others are significantly negative.

Our studies thus far indicate that quantitative measures of interaction and coordination of movements are fundamental to the understanding of complex motion cycles. The problems of compensation of movements as brought about through fatigue and changes in motivation may be experimentally evaluated through measurement of movement interaction and coordination. We believe that many problems of human engineering involve the adjustment of controls and materials in work tasks in order to facilitate natural or individualized coordinations, tempos or rhythms in movement.

Psychological Dimensions of Performance

As noted above, motion analysis of work discloses that performance variables such as learning, perception, motivation, stress, and fatigue affect differently the component manipulative and travel movements and their interactions. These differential effects were observed first in relation to learning (22). Figure 7 shows these differential effects for the manipulative and travel movements in a panel control task (15). It will be seen that practice in this task (ten trials each day for six days) produced a marked change in the mean duration and variability of the manipulative movements but little or no change in the duration of the travel movement.

Learning and Performance

The differential learning effects in performance are not a superficial occurrence. They are seen in complex motion cycles as well as in simpler movements. They are specifically related to the perceptual complexity and reactive complexity of the task as well as to motivation and perceptual stress (10, 11, 23). For example, in a dial-setting task, involving a pattern of motion exactly like the switch-turning operation mentioned above but requiring increased precision in the manipulative movement, the effects of practice on the travel and manipulative movements are more or less similar.

In general, we can summarize the differential effects of learning on manipulative and travel movements as follows. Manipulative movements are organized primarily with reference to the space characteristics of objects and surfaces in the environment. In any new task, these movements will show

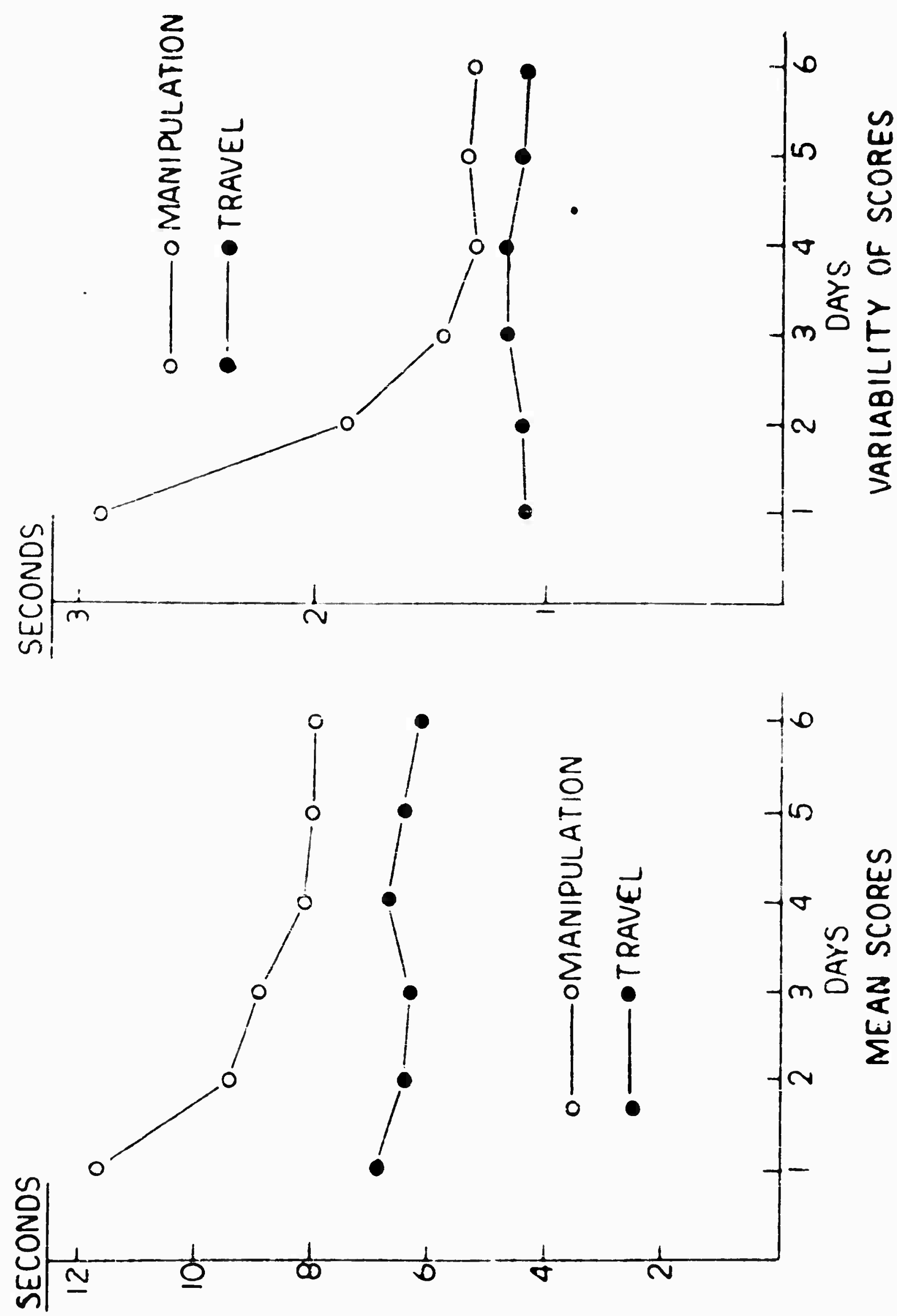

Fig. 7. The learning differential in the different component movements of the motions of a panel control task.

a marked learning effect, inasmuch as practice brings about greater articulation of the manipulative movements with reference to the specific space characteristics of the situation. Increasing the perceptual and reactive complexity of the task or any change in established modes of posture and travel motion will also serve to increase the magnitude of change in manipulation movements as a function of practice.

The travel movements in performance are structured with reference to both the postural basis of motion and environmental space factors. We expect limited change in these movements with learning, if the task organization requires normal modes of posture and scope of movement. We expect marked changes in these movements with learning if the orientation of the body with respect to its spatial environment is unusual, or if the perceptual and reactive complexity of the task involves setting up new or unusual rhythms in motion.

Motivation and Performance

There are many problems relating to the motivational basis of performance. Thus far we have been concerned experimentally with three aspects of this general field. In two preliminary studies, we have examined the effects of self-pacing upon the travel and manipulative movements in gait and in panel-control operations. In general, the results of these studies indicate that, within reasonable limits, the basic organization of travel and manipulative movements is not changed in relation to the speed of pacing, although the absolute durations of the two components are markedly changed.

We have made some attempts to assess the effects of differential knowledge of results about specific component movements on performance. These experiments have turned out to be unusually complex. Thus far the findings seem to be that providing knowledge of results for one component movement in an assembly task has much the same effect as providing such knowledge about the whole task.

We believe that motion analysis methods may be used to assess what we call psychological reserve in performance. We define this reserve as the discrepancy in duration of motion components between self-regulated normal and maximum pace for task periods of short duration. This motivational reserve is being studied presently in relation to age.

Stress and Performance

All of the problems of motivation and performance are, of course, tied up with the problems of stress and emotion. We have been interested in these problems with special reference to certain theoretical ideas about the neuromotor organization of the component movements of motion. A guiding hypothesis has been that space-articulated manipulative movements are regulated primarily at the cortical level, and are to some extent independent of postural mechanisms of control. Travel movements, in contrast, which are structured by posture as well as by space, are regulated at both the cortical and subcortical level. These travel movements reflect more directly than the manipulative movements variations in the subcortical activation systems of the brain. In other words we expect travel movements to show the effects of physiological stress more quickly and more clearly than the finer manipulative movements.

Studies conducted in cooperation with the University of Minnesota

Laboratory of Physiological Hygiene (2, 4) support these hypotheses. Travel movements in performance are seriously retarded by semi-starvation (1000 calories per day for 24 days) and thirst stress (30 percent of water intake for a period of 5 days) in contrast to the manipulative movements, which are affected very little.

Our findings also show that only the travel components of manual skill display systematic diurnal changes in performance level. Harris (1), working in our laboratory, has found that sleep loss affects mainly the travel movements in motion. In addition, he observed that diurnal changes in performance during two days of sleep loss appeared only in the travel movements.

The statements just made apply to physiological stress and its accompanying systemic fatigue. Local or reactive fatigue affects the components movements of performance in a somewhat different way. With high rates of work, the manipulative movements in the task may be the first to be affected, followed somewhat later by deterioration in the larger travel movements.

The effects of emotional stress and anxiety on motion and of certain drugs on performance present problems of analysis like those involved in physiological stress and fatigue (18). In this area also, we believe that a broad operational theory of motion, from which specific hypotheses can be generated and tested, is of value. Presently, we are attempting to apply our electronic techniques to the assessment of the effects of some of the tranquilizing drugs on gait, handwriting, and other performance tasks.

Performance and Perception

It is necessary to put considerable theoretical emphasis on the perceptual dimensions of performance. All motions, simple and complex, are not only space-structured but affected by general environmental variables of temperature, humidity, ventilation, atmospheric pressure, light, and sound, but they vary as a function of the perceptual dimensions of relative direction, distance, complexity of visual pattern, and precision of input information necessary for their control (3, 6). We have approached this general subject of perception and human motion from several directions (6, 7, 8, 12, 14).

The duration of movement components in an assembly task has been measured as a function of the relative degree of complexity of perceptual information for control of the motion (11). Increase in complexity generally raises the duration of all components, particularly that of the loaded travel and assembly movements. The effects of changing perceptual complexity in a task have also been compared with the effects of varying the reactive complexity (or number of distinctive movements) involved in the task. The effects of the two types of variation on performance are much the same.

Another problem which has interested us very much is the nature of interaction between perceptual discrimination and different component movements in an assembly cycle (13). The assembly set-up diagrammed in Figure 8 shows the arrangements used for these studies. As a part of this work task, a discrimination of the color of pins (to be placed in separate parts of an assembly plate) can be required in conjunction with the grasp movement, the loaded travel movement, the assembly movement, or the return movement of the cycle. The results show that the perceptually loaded

component is always increased in duration over what it would be under conditions of a lesser perceptual load But other components in the cycle also may be affected by the locus of the discrimination, especially if discrimination is required in the loaded-travel or assembly phases of the cycle. Thus, we say that perception is an active behavioral process that interacts with the primary components of motion, and that the relative timing of perception and component movements will determine the rhythm as well as as the precision and duration of the whole motion cycle. It may be noted that some of the most fundamental problems of human engineering and design of complex machines involve these problems of interaction of perceptual response and specific movements in a pattern of performance.

A third basic problem of perception and motion is related to the interaction of sensory input sources (particularly visual and kinesthetic) that control the space dimensions of travel and manipulative movements in complex performance Prior observation of effects of inversion and reversal of the visual field upon performance provide a general introduction to this problem We have set up explicit hypotheses and experimental designs for analyzing and comparing the effects of inversion of movements (kinesthetic inversion) and inversion of the visual field upon the component movements in motion (9) For these studies we have used special techniques of motion analysis of handwriting, illustrated in Figure 9. To invert the visual field without producing other forms of distortion we employ a large right-angle prism which permits clear vison of the writing field. Results show, as predicted, that combined visual and kinesthetic inversion of the sensory input of motion produces far greater disturbances in coordination than either visual or kinesthetic inversion alone Moreover, subjects generally cannot adjust completely to the combined visual and kinesthetic inversion. Manipulative movements recover less rapidly than travel movements under these altered conditions, a result which had been predicted from the general hypothesis that manipulative movements are more highly articulated spacewise than travel movements

These questions of the perceptual space factors in the control of motion constitute some of the most fundamental problems of remote control and human guidance of complex machines. Every motion has its primary visual space field of performance which may or may not be effectively duplicated in the design of the automobile, the truck, the aircaft or the ballistic control system In cooperation with W. M Smith of Princeton University, whose original suggestions initiated this work, we have applied closed circuit television to the analysis of the relative space organization and control of human performance (21). The illustration in Figure 5 shows how such methods are used to study the effects of displacing the visual field of performance on assembly motions. The diagram in Figure 10 also illustrates how the relative size of the performance field can be changed through the use of closed circuit television, in order to analyze the effects of size constancy on performance.

It should be noted that we look upon these television techniques of studying human performance as an essential step toward a more significant level of analysis of the space and time organization of motion. The television tape recorder, which is presently an expensive broadcast tool, will serve in the near future as an experimental device for delaying the visual feedback on one's own motions. This instrument will thus make possible precise control of the relative time dimensions of kinesthetic and visual

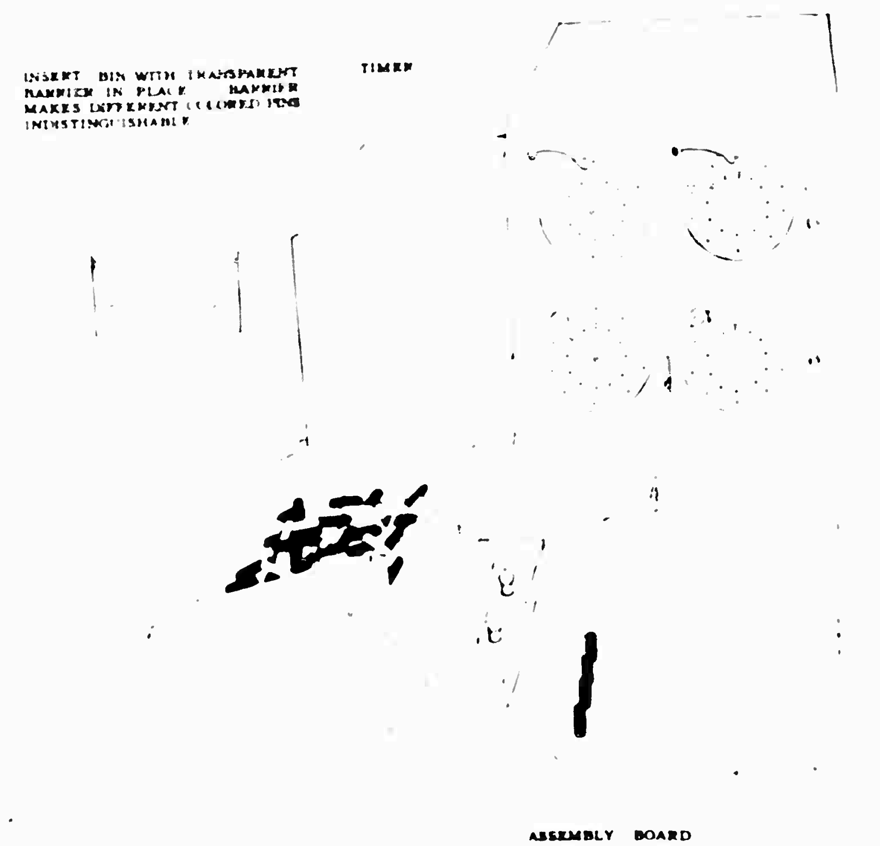

Fig. 8. The arrangement of task materials and motion analyzer units for studying the interactions of perceptual discriminations and specific movements in assembly motions.

Fig. 9. Arrangement of task materials and optical unit for analysis of the relative effects of kinesthetic inversion and inversion of the visual field upon the component movements in handwriting.

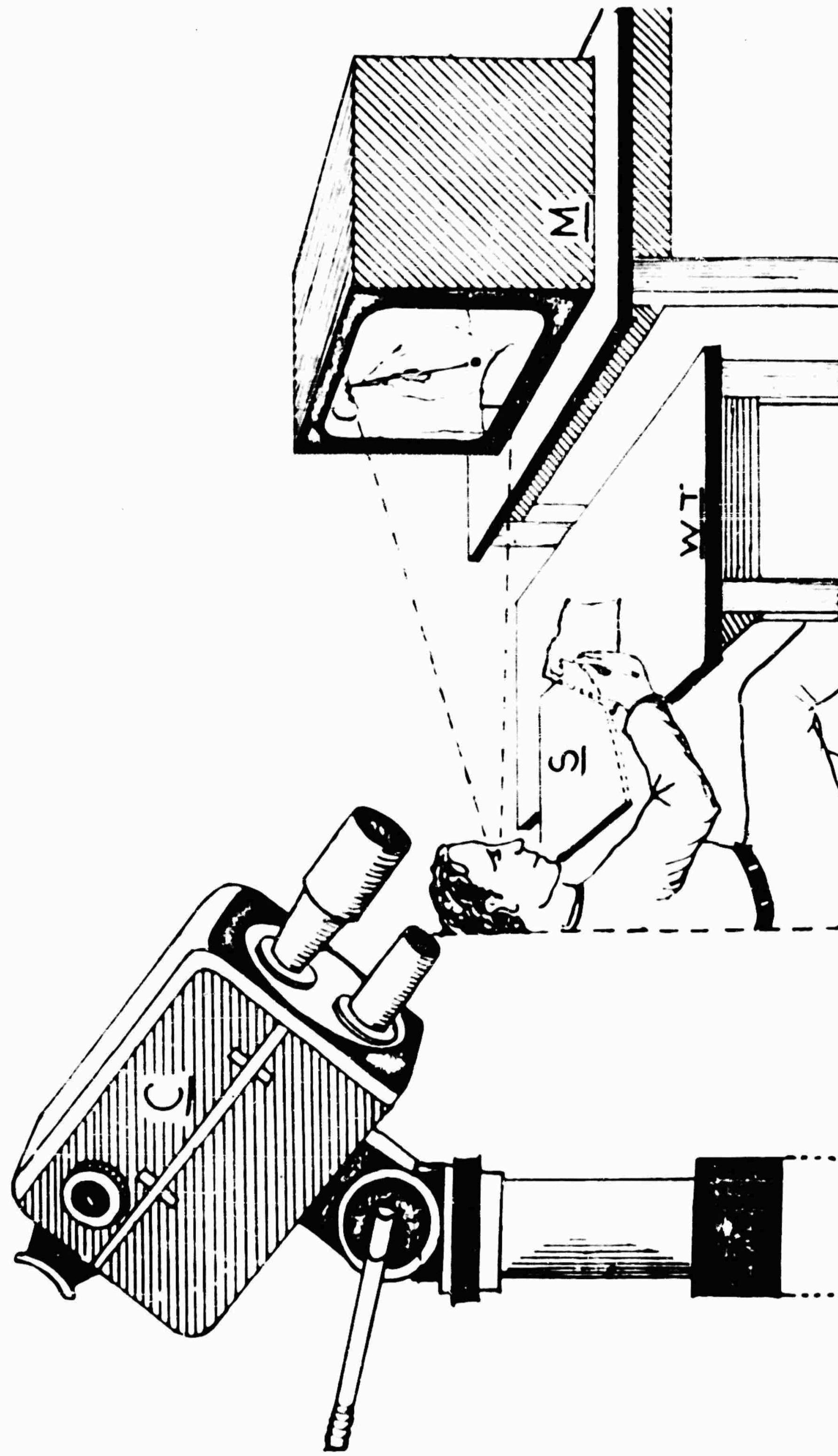

Fig. 10. Closed circuit television applied to the analysis of perceptual stress and of the effects if displacement and size distortion of the performance field of handwriting.

factors in motion (21). We are on the threshold of achieving not only economical analyses of the component movements in many functional patterns of human performance, but of measuring the inter-relationships of the fundamental space and time dimensions in coordinated motion.

Scientific Problems of Performance Assessment

This description of our efforts to measure human performance would not be complete without some indication of its general significance. We think of performance study as one objective approach to many of the problems of human behavior, such as the nature of work, the effects of stress, the influence of drugs, the biochemistry of neuromuscular activity, and the nature of behavior disorders.

Performance measurement is not an end in itself. We strive for insight into the various patterns of human adaptation, internally and externally, in both health and disease. Measuring performance can aid our understanding of such patterns if we ask the right questions. External performance interacts with internal, physiological processes. It is both cause and effect in adaptation. Our measurements of external performance must always be related to known internal states of the individual.

Our ideas of performance assessment may be predicted to evolve according to the principles of systems analyses. Man is a behaving, adapting organism, not a simple reaction machine. Accordingly, performance measurement must be related to quantitative expressions of the different psychological and physiological dimensions of adaptation — development, aging, learning, thinking, perception, motivation, and emotion — and their interactions at different levels of activity within the body.

Rapid developments in the electronics field promise much for the understanding of all phases of performance. The modern digital computer provides the means of comprehensive analysis of data in relation to both empirical tests and theoretical models. The techniques of automated data recording promise even more for performance study. The events of behavioral adaptation are probably no more complex than the events of complex physical systems, but these events of adaptation take place slowly, at a snail's pace, changing at rates beyond the scope of human insight. Modern tape recording methods make it possible to extend economically the scope of behavioral and physiological recording and to utilize effectively the digital computer in the solution of performance problems. The electronic methods of performance study described here represent a critical step in adapting these automated data recording techniques to solution of problems of performance.

SUMMARY

The following main points were covered in this survey of the application of scientific motion analysis methods to the assessment of performance.

1) Human performance is an aspect of organismic interaction which must be assessed at the behavioral level in terms of postural, travel, and manipulative components of motion in different types of activities. Electronic methods of motion analysis provide one means of measuring these different component movements in performance.

2) The electronic techniques of motion study are based upon a

principle of using the body as an electronic key in order to time automatically the duration of manipulative and travel movements in manual skill, in panel control operations, in handwriting, and in gait.

3) Movement organization in performance, including movement interaction, tempo, rhythm, and coordiation, may be quantified in terms of the manipulation-travel ratio, the manipulative-travel correlation, and other special measures of movement relationships.

4) Learning has different effects upon the manipulative and travel components of motion, which must be understood in terms of the basic neuromotor organization as well as in terms of interactions between learning and perception.

5) Motivation alters the absolute level of the duration of component movements in motion but does not appear to change fundamentally the organization of coordination of these movements.

6) Systemic stress of any sort, including semi-starvation, extreme thirst, and loss of sleep, affect primarily the postural and travel movements in performance. The diurnal changes in work capacity are observed primarily as alterations in travel movements. The effects of emotional stress on different phases of motion have not, as yet, been clarified.

7) Many perceptual factors influence performance, including perceptual load or complexity, perceptual stress, interaction of perception and specific movements of travel and manipulation, and the relative space organization of different sensory processes in the control of movements. Specific motion analysis methods have been developed in order to quantify these aspects of perceptual-motor action. The application of closed circuit television to analysis of these perceptual problems of motion are especially promising.

8) The scientific methods of motion analysis, described in this report, are an essential step in the automated recording and analysis of performance data by means of modern electronic computing methods.

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THE DIGESTIVE SYSTEM

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The classical aspects of the digestive process are fairly well known and need not be discussed here. The effects of moderate muscular activity upon secretion and motility are not very striking and the normal variations from day to day in these functions are rather large and not very predictable.

There are certain facts which have come to light recently, however, which may have some bearing upon the subject under discussion and that is the importance of the gastrointestinal tract itself as part of the protein reserve of the body. The mucosa of the small intestine is possiby the most labile source of protein in the body. Histological slides of this tissue always reveal numerous mitotic figures which suggest intense cellular and hence metabolic activity. It is well know that the intestinal mucosa repairs itself very readily.

It is interesting to consider the amino acid mixture which is found in the gut lumen after feeding quite different meals (3). This work was undertaken in order to test the idea, often expressed, that variations in biological value of certain proteins might be attributed to different rates of release of individual essential amino acids during digestion in the lumen of the gut.

Egg albumin was used as an example of high grade protein, and zein was used as an extreme example of protein of low biological value. A non-protein mixture of sugar and lard was used as a control test meal. Dogs were kept on a normal laboratory diet until the day before the experiment. After fasting 24 hours they were fed the test meals. Approximately one and one-half hours later the dogs were sacrificed, and the stomach, duodenum, jejunum, upper and lower ileum were removed separately and the contents taken out, quickly frozen, and prepared for amino acid analysis.

Sixteen free amino acids, including all the essentials, were determined by microbiological techniques. It was surprising to learn that the mole ratios of the free amino acids in the lumen resembled neither egg albumin nor zein. In the stomach contents it was possible to recognize the amino acid pattern of the test meal protein but in the duodenum it became less distinct and from the jejunum to the ileum it was impossible to identify the test meal from an examination of the amino acids in the contents. Zein, which is virtually devoid of tryptophane and lysine, yielded the same amino acids and in the same ratios as egg albumin. Tryptophane and lysine, which were absent from the test meal, appeared in the intestinal contents in about the same proportions as they did when egg albumin was fed. More surprising still was the fact that when a mixture of sugar and lard was fed the amino acid pattern remained the same as when egg albumin or zein were fed.

These results have since been confirmed in a study of the digestibility of irradiated meat and lard (4). In general it seems that the nature of a meal exerts little or no influence on the amino acid mixture present in the lumen of the gut during digestion. This phenomenon suggests the presence of a sort of homeostatic mechanism which must play an important part in

determining the amino acid composition of the portal blood, so that the liver (almost regardless of what is eaten) is supplied with a mixture of amino acids which presumably is optimal for the synthesis of protein.

What is the source of endogenous amino acids which appear in the lumen of the gut? It is useful to recall that all of the hydrolytic enzymes are proteins. Up to the present it has been easy to fall into the error of thinking that, since their function is chiefly catalytic, they are present only in very small amounts. The evidence suggests that they may be secreted in rather large amounts and that they are virtually completely auto-digested and recovered from the gut as amino acids. The amino acid composition of five different hydrolytic enzymes of the gut was furnished by R. J. Block and from these data certain computations were made. It was assumed that the amount of enzyme protein secreted into the lumen was equal to the amount of protein in the test meals and the resultant amino acid mole ratios were calculated. They were surprisingly close to what was found by direct experiments (2). This concept seems too simple to be true, but there can be no doubt that digestive enzymes, the mucoproteins and other proteins that are secreted, plus the sloughed mucosa, must contribute importantly to the amino acid mixture found in the lumen of the gut.

Another aspect of this work, which is still in progress, was designed to indicate the extent and the mobility of the protein reserves in different parts of the gastro-intestinal tract, the liver, the pancreas, and the whole rat, at various stages of fasting and during subsistence on a protein-free diet for as long as 16 days (1).

The protein reserve of the small intestine, pancreas, and liver drop precipitously and in eight days of fasting they are less than half of what they were at the beginning. On re-alimentation with egg albumin recovery occurs promptly. The small intestine recovers most promptly, followed by the liver, pancreas, and stomach, in that order. In the first 24 hours of re-alimentation the pancreas and stomach actually lose still more protein before recovery begins. This is probably due to the secretory demands made on these organs upon ingestion of a meal, without having immediate access to the exogenous amino acids for replenishment of their own protein stores. The mucosa of the small gut serves to transfer amino acids from lumen to portal circulation and hence has first call on them as they pass through. The liver is next in line by virtue of being in the portal stream. The stomach and pancreas must wait until the systemic blood carries enough of the exogenous amino acids to facilitate the replenishment of their protein stores.

Thus far the evidence indicates that the hydrolytic enzymes and other proteins of the digestive secretions, plus sloughed mucosa of the small intestine represent one of the largest and most mobile protein reserves of the body.

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ADDITIONAL OBSERVATIONS ON PERFORMANCE AND THE DIGESTIVE SYSTEM

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I am intrigued by the line of discussion Dr. Nasset has brought up. I never thought about it before, but just a fast calculation tells me that the human pancreas can put into the gut as much as 20 grams of protein per day, in the form of digestive enzymes.

Also, I wish to point out that I don't think we can think of the digestive system in the same terms as we have been discussing the other systems. In the cases of the cardiovascular system and the neuromuscular system, we are thinking of their direct contribution to performance. These may become limiting factors in performance. To no important extent can the digestive system become a limiting factor in performance, in the sense that work capacity can be exceeded, with other limiting factors having come into play, long before the normal ability of the digestive system to assimilate energy has been exhausted.

So, we have to look at the opposite side of the coin for clues of relationship of the digestive system to performance, and that is the effect of various degrees of performance upon the activities of the digestive tract. Here, I believe, we have relatively little quantitative information. In general, the secretory activity and the motor activity (which are the two things we can best measure quantitatively) do not become significantly depressed during moderate muscular activity. However, they do become disordered at extremely high work levels—the familiar vomiting of the athlete after he has run his prize winning dash, for example. I certainly cannot submit quantitative data on this aspect of the problem, but I think it is one that might be of some interest.

The other thing that comes to my mind in this area is the relationship of digestive functions to the finer types of motor performance. Here I have particularly in mind studies such as Kate Daum and her coworkers have made on the effect of skipping breakfast on various measures of psychomotor performance, and here again I think we have only the crudest type of indication of these relationships, and need more information.

III APPLICATION OF STANDARD WORK TESTS

OPENING REMARKS

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In the preceding section of our discussions we have considered in some detail those bodily functions which are affected by work or which, in turn, affect bodily performance. The question now before the house is how, in the light of this knowledge, we can devise tests of bodily response to work that will enable us to determine how much disturbance to bodily function is being created, and perhaps more importantly, how well the individual being tested is capable of carrying out a given task. In engineering terms, we wish to know, not only what strain is being experienced as a result of the applied stress, but also how well the test item will perform under given circumstances. To continue the engineering terms, we obviously need some system of non-destructive testing. For various reasons it is desirable that the individual being tested survive to work another day.

We could, of course, measure the degree of disturbance caused by various levels of work to each of the bodily functions considered in the previous section. But, apart from the confusion of data that would result, we would be faced by the serious question of how much weight to attach to each of the observed disturbances. A straight average of proportional responses would be neither intellectually satsifying nor physiologically sound. We need to be selective, selective in the reactions that we observe, and selective in the type of stress that we impose. The reactions must be such that disturbances are readily measured, respond proportionately to stress over a wide range of stress, have real physiological significance, and are relatable in some way to actual performance. The type of stress must bear some demonstrable, and preferably easily understood, relationship to actual practice — because, after all, the ultimate purpose of our work is improvement or prediction of human efficiency in the real world. The test performance should be such that it can be fairly easily standardized and conducted by various people under various circumstances with results that will be truly comparable. It would be very nice if the test could include some easily recognizable breakpoints, beyond which persistence would be known to carry certain penalties.

Experience has shown us that maximum performance tests are much more easily established than tests at sub-maximal levels of stress. We badly need tests that will give us a quantifiable gradution of response from low to maximum levels of stress. This is not easy. As one who has tried for many years to devise tests of response to thermal stress, without too much success, I will listen with considerable interest to the proposals which will follow.

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TREADMILL TESTS OF PERFORMANCE CAPACITY IN DOGS

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In 1913 there appeared a small volume entitled *The Fitness of the Environment* by L. J. Henderson. Henderson distinguished three general aspects: (1) the basic nature of the physical elements in the cosmos, (2) the specific combinations of these elements on the earth, and (3) the fitting of living systems into this environment. Capacity to perform, insofar as it involves maintenance of health, adjustment to imposed work tasks and the changes in the environment, is implicit in the latter aspect of fitness. Consequently, in examining performance and the factors affecting performance capacity, we are studying Henderson's third component of fitness.

While the problem of assessing fitness remains complex and controversial, there is agreement that physical work tests generally show promise for measuring important parameters of fitness. While such tests measure directly only fitness for physical performance, the relevance to health, rehabilitation, as well as occupational and military performance is apparent.

In performance tests conducted in our laboratory we have emphasized treadmill running in dogs. This interest stems from the nature of our researches, that is, experimental studies to determine the effects of nutritional and environmental stresses on fitness and physical work capacity. Treadmill running has been selected as the testing procedure since it permits adjusting the intensity of work, provides direct as well as indirect measures of performance capacity, and represents a type of physical effort the effects of which can be compared directly with measures taken in man. Additionally, treadmill running has the advantage of requiring relatively little training. Consequently, the necessity for exessively long-term conditioning to assure consistent results is obviated.

This paper presents the methodology of treadmill tests of performance capacity in dogs, a description of the body responses to work of graded intensity, and an indication of some of the important factors limiting performance in the dog, along with recommendations for applications to the study of the relationships between performance and dietary variations.

Methods

Each treadmill used here provides a running space of 58 inches by 18 inches on a rubberized non-skid belt. The belt is driven by a 1½ horsepower synchronous motor operating through a variable transmission. The belts are calibrated for speeds from 1.5 to 14.6 m.p.h. Grades are determined by geometrical measurement and expressed as degrees of incline. An electric barrier mounted at the rear of each mill provides the stimulus (180 volts; low amperage) for running to exhaustion. Periodic wetting of the hind quarters of the animal serves to increase the aversion to the stimulator and promotes maximum performance. The end point in exhaustive running tests is determined by failure of the animal to respond to six consecutive shocks

from the grid. Terminally, the dogs show typical signs of fatigue such as refusal to rise, muscle tremor, and spasm.

A cardiotachometer, telethermometer, and chain-compensated gasometers are used to determine heart rate, body temperatures, and respiratory gas exchange before, during, and after work. These data and the results of blood analyses provide a descriptive evaluation of the effects of exercise and hard work, and form the basis for indirect, physiologic and biochemical, criteria of performance capacity. Figures 1 and 2 demonstrate the collection of expired air, measurements of pulse rate and body temperature, and collection of water loss from the oral surfaces during aerobic bouts of work.

Typically, the animals are given two to three weeks of technical training to assure consistent responses.

Usually the treadmill speed is held constant at 3.63 m.p.h. For 10kg. dogs 30-35 cm. in height, this provides a comfortable pace of 140 strides per minute with a step length of 35 cm. Work intensity is adjusted by hydraulically varying the grade from 0 to 22 degrees of incline.

Enviromental conditions provide a constant temperature, humidity, noise level, and lighting. Most tests are conducted at 65° F. and 53 percent relative humidity.

While we have collected a large body of data as a result of tests administered to mongrel dogs as well as to pure-bred beagle pups, most of the responses set forth below have been obtained in tests conducted with beagles approximately one year of age.

Results and Discussion

Effect of increasing grade on energy expenditure: Work metabolism has been studied in tests of graded intensity. For collecting expired air samples, the dogs are fitted with especially constructed respiratory masks, and trained to accept the mask without breaking stride. Routinely, one-minute gas samples are collected at 20 minutes and 39 minutes of a standard 40-minute work test and analyzed for oxygen and carbon dioxide content. Calculations of caloric expenditure are made from the Tables of Zuntz as provided by Peters and Van Slyke (1). No corrections are made for protein metabolism. Figure 3 shows the average increase in caloric expenditure with grade. The curves are similar in all animals tested. The relationship is described by the linear form $Y = 0.022X + .14$, where Y is the calories expended per kilogram per minute and X is the degree of treadmill inclination. On the basis of replicate measures of oxygen uptake, the coefficient of variability (100 S. D./Mean) has been computed to be 10 percent and independent of the workload. This error term establishes the precision for this particular measure.

Work efficiency: Capacity to perform is in general related to work efficiency. The efficiencies of grade climbing are determined according to the method of Smith (2). Generally, the highest efficiency is reached at eight degrees of incline, and for all dogs it decreases at the lower and higher grades (Table 1). The maximum efficiency attained varies from 17.5 to 28.7 percent.

Maximum oxygen uptake: The maximum oxygen uptake is generally

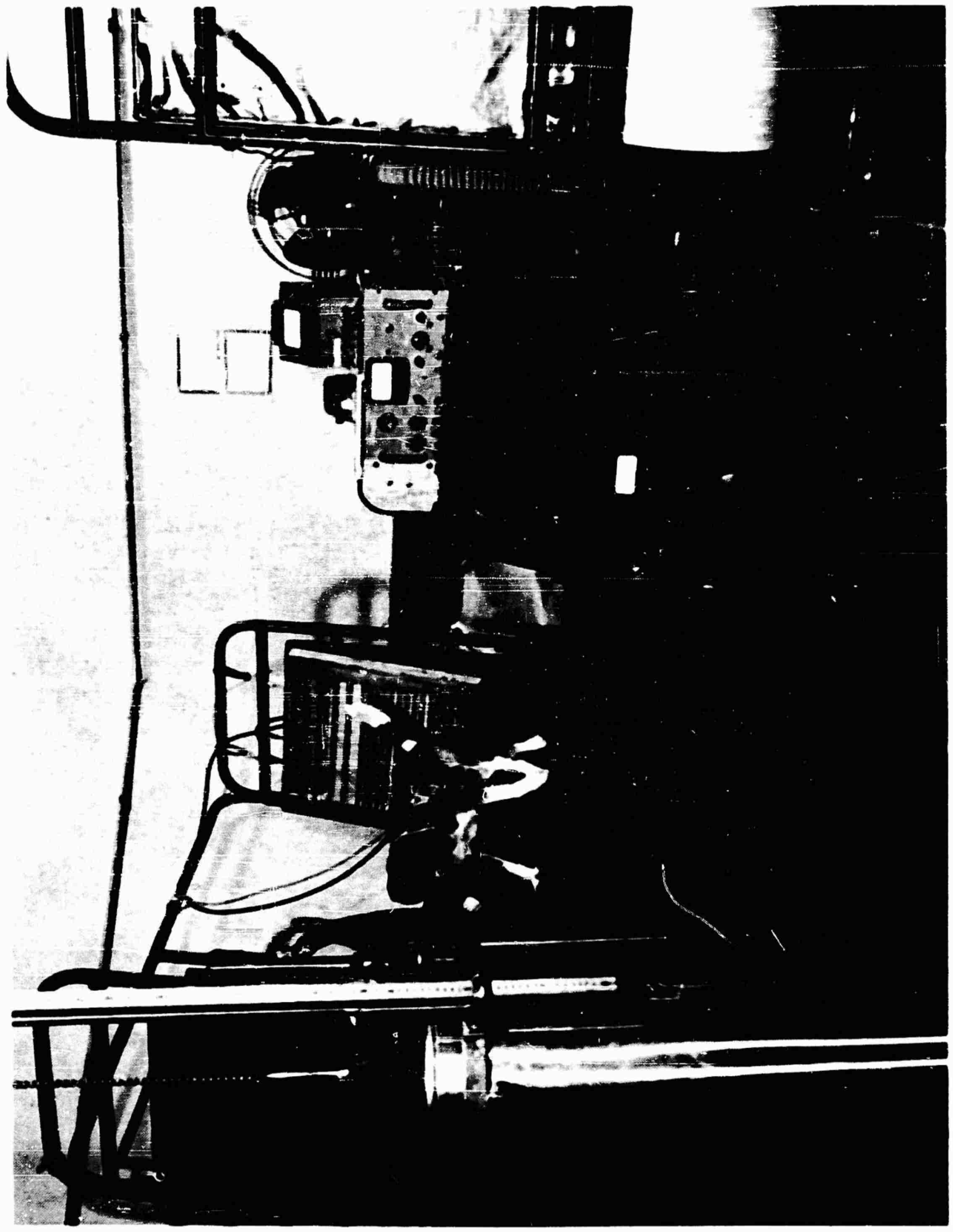

Figure 1. Measurement of respiratory gas exchange, heart rate and rectal temperature in the dog during an aerobic bout of work on the motor-driven treadmill.

Figure 2. Collection of oral fluid loss and measurement of body temperature during treadmill tests of performance capacity in the dog.

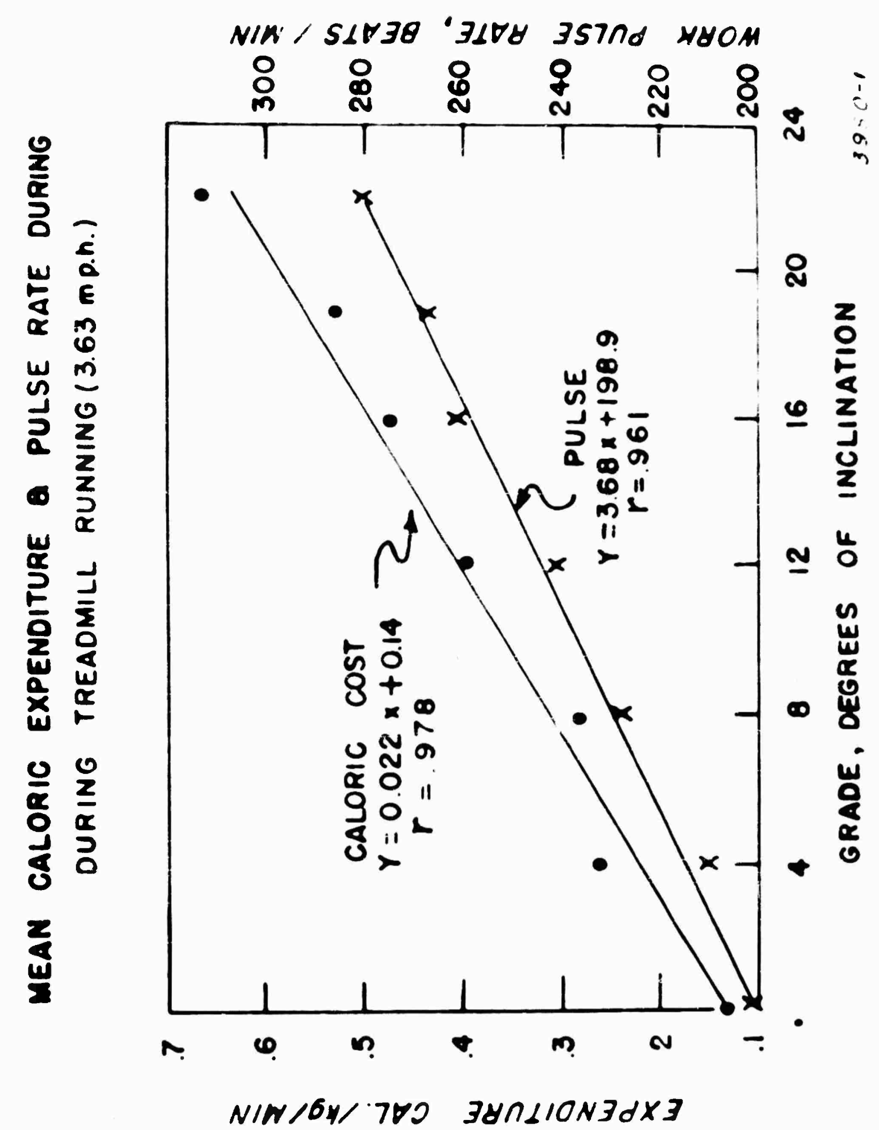

Figure 3. Effect of increasing grade on the mean caloric expenditure and pulse rate during treadmill running (3.63 m.p.h.) in 6 pure-bred male beagle dogs at one year of age.

Continuing efforts are being made to develop rapid testing procedures which by a single or relatively few criteria will distinguish fitness in animal populations. In the meantime we have had a good deal of success in applying the long-sustained work test in studying the effects of water and carbohydrate supplementation as well as effect of starvation on performance capacity. For long-sustained running trials, the work is aerobic in nature, work efficiency is high, and calorie expenditure is maximized while effect of body temperature and changes in the blood gas content are minimized.

TABLE 1.

PERCENT WORK EFFICIENCY DURING GRADE RUNNING
(3.63 mph)

Dog No.	Grade					
	4°	8°	12°	16°	19°	22°
22	9.8	17.5*	14.9	15.6	16.3	15.8
23	12.7	28.7*	21.6	20.4	20.2	15.6
33	14.2	19.3	19.8	19.7	20.1*	16.3
34	13.3	22.5*	15.4	18.2	19.7	16.6
35	14.9	21.8*	21.0	20.8	19.8	15.4
Mean	12.9	21.9	18.5	18.9	19.2	15.9

* Highest efficiency

TABLE 2.

Summary of the Responses of Dogs to Exhausting Work of Graded Intensity

All tests conducted at a constant speed of 3.63 mph at grades of 22, 15, and 10 degrees of incline

Characteristic	Grade 22°	Grade 15°	Grade 10°
1. % peak effort*	97.2 ± 4.23	55.2 ± 4.29	43.5 ± 4.57
2. Running time, min.	16 — 31	40 —166	325 ± 729
3. Total energy expenditure, Cal./kg.	**17.0 ± 3.73	**49.0 ± 19.16	138.0 ± 38.21
4. Maximum pulse/min.	296 ± 10.12	303 ± 17.08	249 ± 16.24
5. Maximum rectal temp., of	108.7 ± 0.69	107.4 ± 0.53	105.3 ± 0.85
6. O_2 debt, cal.	12.1 ± 7.08	22.0 ± 10.89	
7. Δ Blood glucose, mg. %		+ 11.0	— 30.0
8. Δ Blood lactate, mg. %		+ 30.3	+ 1.3
9. Δ Venous O_2, vol. %		+ 4.8	— 0.5
10. Δ Venous CO_2, vol. %		— 17.1	— 6.4

$$\text{* \% of peak effort} = \frac{\text{observed } O_2 \text{ uptake} \times 100}{\text{maximum } O_2 \text{ uptake}}$$

**Includes the oxygen debt

taken as a measure of performance capacity of the cardiovascular-respiratory system. In a broader sense it has been used as a criterion of over-all performance capacity. Maximum oxygen uptake has been periodically measured in dogs varying from 21 to 49 weeks of age. Depending on the age and size of the animal, speeds of 3.6 to 10 m.p.h. and grades varying from 10 to 22 degrees of incline are required to elicit this response. The maximum value is taken when, for a constant speed, additional treadmill inclination of 4° fails to increase the response. In eight- to twelve-kilogram dogs this represents an increased work intensity of 0.128 to 0.192 Cal./min. Figure 4 shows the relationship between the maximum oxygen uptake and age. The values show a marked tendency to increase with age from 60 cc./kg./min. at five months of age to 135 cc./kg./min. at approximately one year of age.

An examination has been made of total endurance capacity in relation to the maximum oxygen uptake. Running time to exhaustion and the maximum oxygen uptake have been determined independently on three separate occasions over a three-week period. For measuring maximum duration of running, a speed of 3.63 m.p.h. and 15 degrees of incline have been used. These data are presented in Figure 5. While a significant difference may be shown in comparing the average running time of dogs #22 and #33 with that of dogs #34 and #40 — 109 minutes and 156 minutes, respectively (Critical Ratio of the means is 5.1) — there is no difference in the average maximum oxygen uptake of 133 and 138 cc./kg./min. Indeed the results of our studies suggest that a difference in the order of 25 cc./kg./min. (2xS.D.) is required to demonstrate differences in the maximum uptake.

Oxygen debt: Relatively short-term exhaustive running trials induce an oxygen debt in the magnitude of six to eight liters of oxygen. The debt is measured routinely during the first 24 minutes of recovery following work. Within 24 minutes approximately 60 to 70 percent of the debt has been repaid (Figure 6). Since this represents the major part of recovery, it is safe to assume that a standard period of 24 minutes adequately measures this function. For determining the total debt, computations are based on predicted one-hour recovery values. Theoretically, this estimates 94 percent of the debt.

Effect of work on the body temperature: Increase in body temperature is a characteristic response to exertion in the dog. The effect of increasing grade on the rectal temperature is shown in Figure 7. For workloads requiring caloric expenditures up to 0.40 Cal./kg./min. the dog is able to maintain for a prolonged period a relatively steady state temperature with only a moderate degree of heat storage. At heavier workloads, body temperature shows a continuous rise with running time.

Body temperature and factors associated with heat exchange play a major role in determining maximum running time. For relatively short-term exhaustive tests a highly significant relationship is obtained between rate of rise in body temperature and maximum running time. The criteria used to derive this relationship are exhaustion, as evidenced by inability of the animals to continue running, and the time during the test required to attain a rectal temperature of 106.0° F. Selection of this particular body temperature is based on our observations of maximum work rectal temperatures of 107.0° F. to 110.1° F. in replicate tests conducted with 18 dogs. Thus, in the dogs studied the temperature of 106.0° F. is one which can be attained by all animals. Moreover, the time required to attain this temperature during

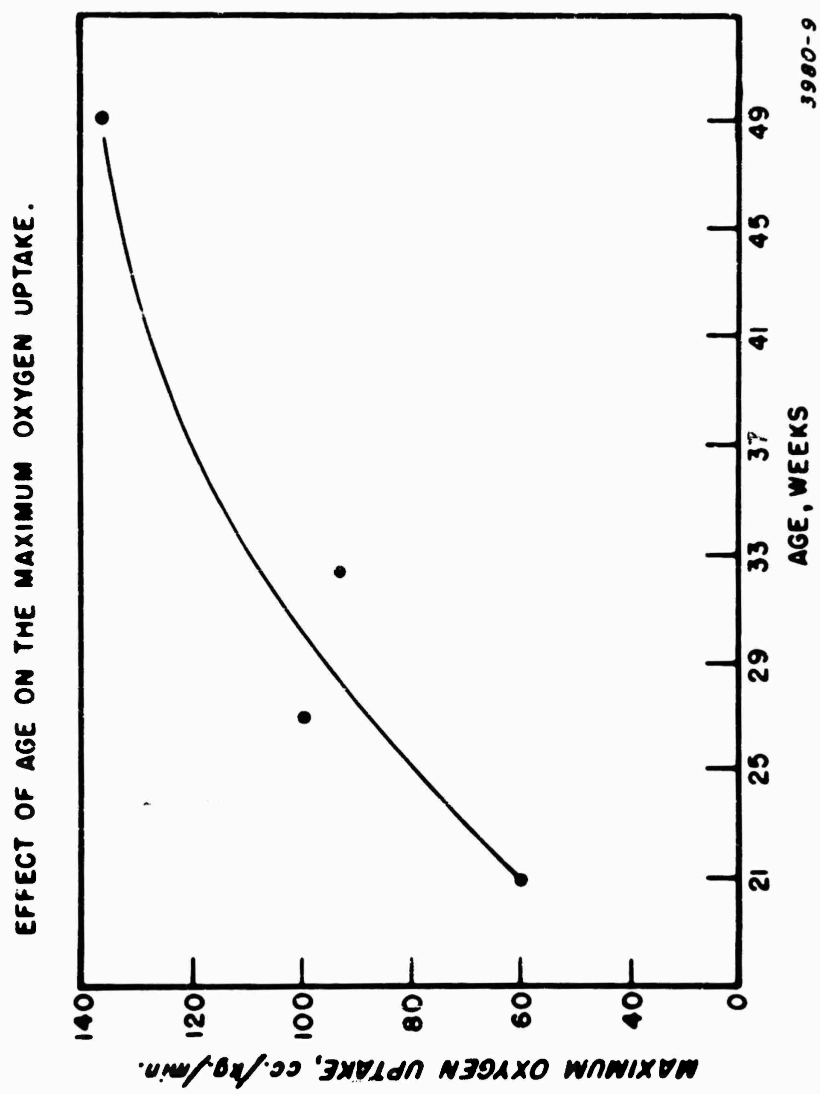

Figure 4. Relationship between maximum oxygen uptake in cc. per kilogram per minute and age in growing dogs. Each point is the mean of replicate determinations in six animals.

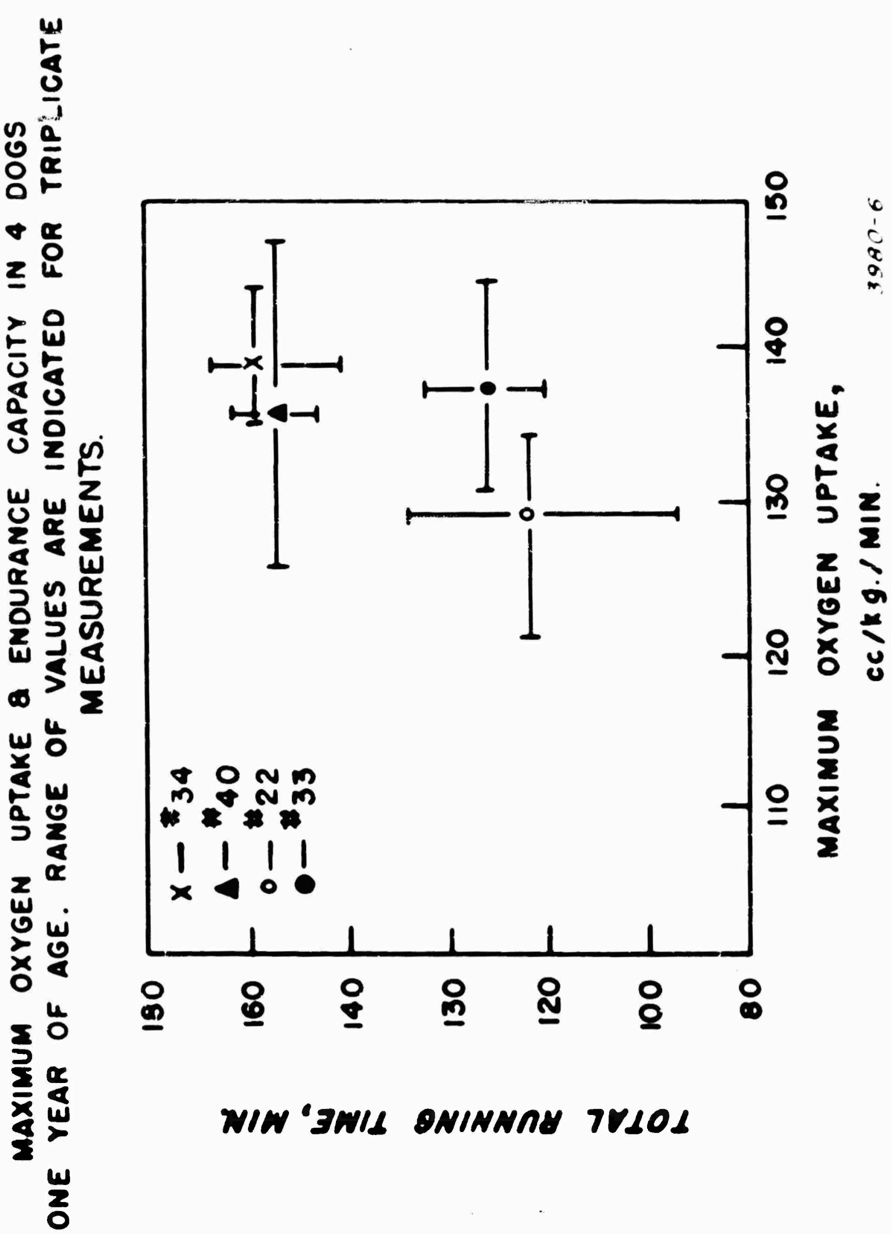

Figure 5. Maximum oxygen uptake v maximum running time in four dogs at one year of age. The maximum O_2 uptake was measured at 5.50 m.p.h. and 19 degrees of inclination. Running time was measured at 3.63 m.p.h. and 15 degrees of inclination. The range of values for triplicate measurements are indicated.

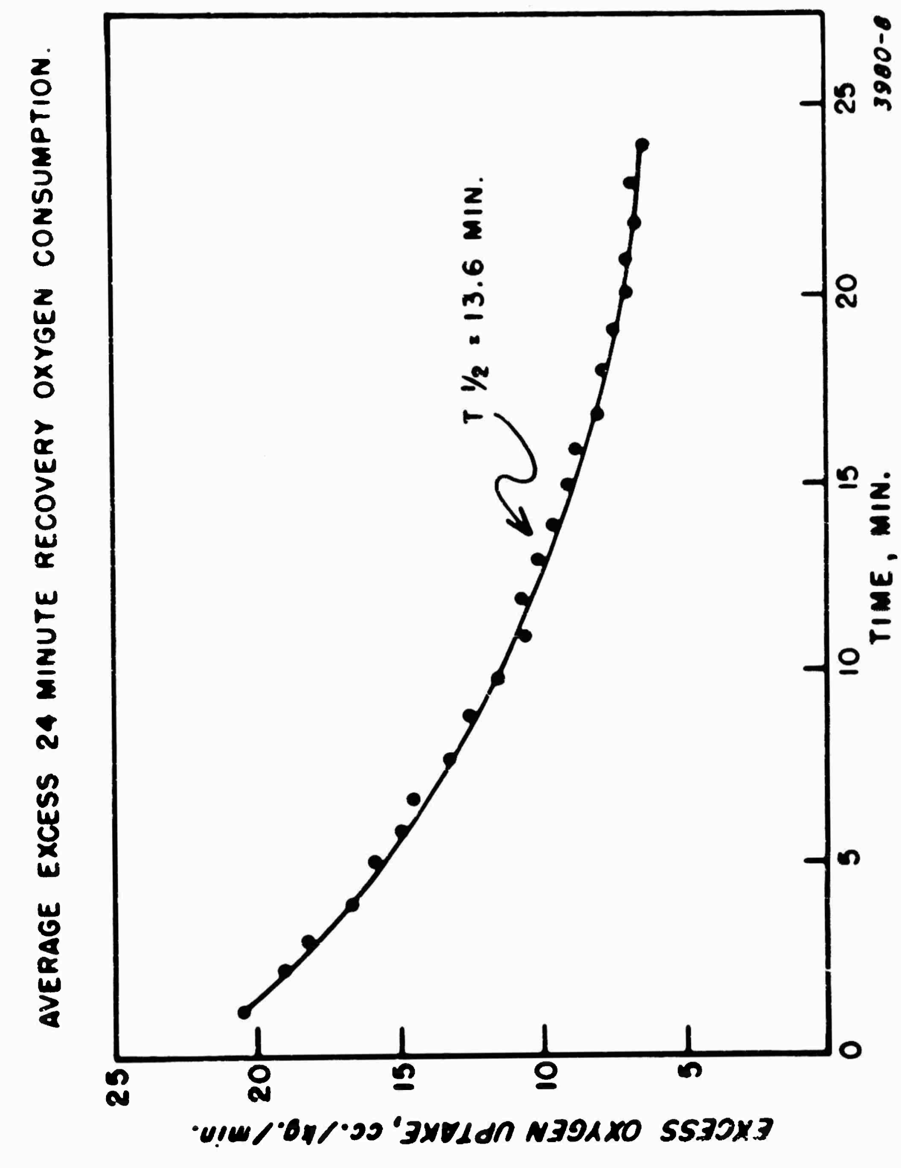

Figure 6. Average excess 24-minute recovery oxygen consumption following a 20-minute run at 4.24 m.p.h. and 20 degrees of inclination. Each point is the mean of determinations made in 12 dogs.

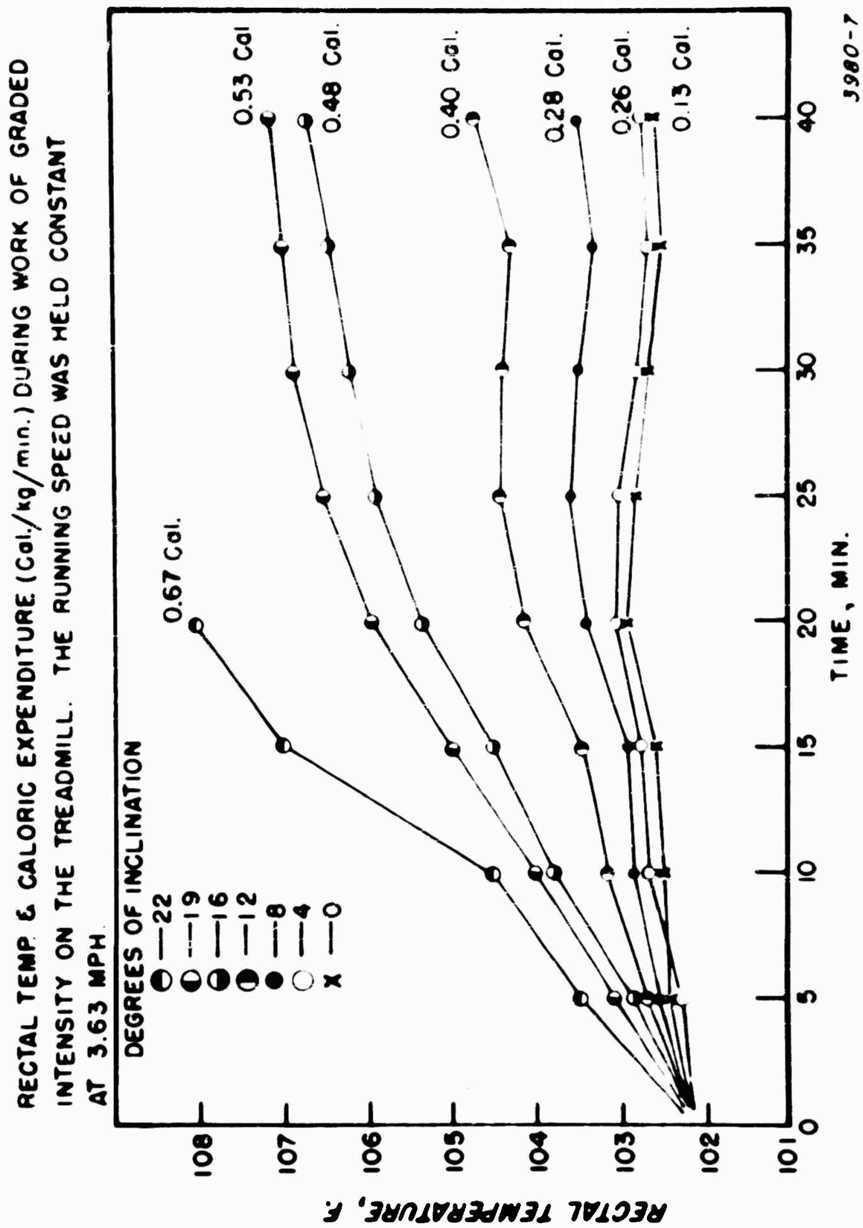

Figure 7. Rectal temperature and caloric expenditure (Cal./Kg./min.) during work of graded intensity. The treadmiil speed has been held constant at 3.63 m.p.h. while the grade varied from 0 to 22 degrees of inclination. Each point is the mean of determinations made in 6 dogs.

an exhausting run distinguishes animals within a population, the short-term runners characteristically showing the more rapid rise in temperature. Figure 8 shows the relationship between the time required to attain a rectal temperature of 106° F. and the maximum running time. The product-moment coefficient of correlation for these two functions is +0.991.

In long, sustained exhaustive running trials, rise in body temperature is less dramatic. Maximum rectal temperatures measured during exhaustive runs of six to nine hours duration vary from 104° to 106° F.

Blood gas content: Treadmill tests in dogs frequently result in marked changes in the venous blood carbon dioxide and oxygen content. In many exhaustive work tests there is a characteristic fall in the whole blood CO_2 tension and a rise in the O_2 tension. These responses are shown below:

Duration of run, min.	40 to 166	*Probability*
Δ CO_2, cc./100ml. blood	—17.1	.01
Δ O_2, cc./100ml. blood	+ 4.8	.05

Thus venous blood carbon dioxide showed a significant decrease from resting values of 43 cc./100ml. to post-exercise values of 25.9, while blood oxygen increased from 15 cc./100ml. at rest to near saturation levels of 19.8 at the termination of work.

Loss of carbon dioxide from the blood is not associated with obvious hyperventilation and "Auspumpung." For example, in the course of over 500 determinations of respiratory gas exchange, R.Q.'s in excess of .99 have been observed on only ten occasions. Therefore, it is likely that blood CO2 loss occurs through a slightly elevated and sustained rate of carbon dioxide elimination as compared to its metabolic production.

Effect of lowered blood CO on the respiratory centers and possible effects on performance bear examination.

Metabolic responses to work: Changes in the post-absorptive blood sugar level are related to work energy expenditure. The product-moment coefficient of correlation between the percent change in the venous blood glucose and excess work calories expended during exhaustive running is —0.835. High-intensity work of relatively short duration results in an elevation of the blood sugar level from resting values of 81 ± 7.0 mg. percent to values as high as 133 mg. percent. For these tests the energy expended for work does not exceed 500 to 600 calories. On the other hand, work expenditures of 600 to 1200 calories lower the blood sugar. We have obtained values as low as 45 mg. percent at the termination of long, sustained exhaustive work.

Our data on the relationship between work calories and blood sugar are in general agreement with the trends shown by Dill *et al* (3), and provide guiding information for selection of tests for studies wherein the blood sugar level is of interest.

For high-intensity tests of relatively short-term duration, the blood lactic acid increases from resting values of 2 to 7 mg. percent to levels of 50 mg. percent. However, work which tends to lower the blood sugar does not materially affect the level of lactic acid.

Measurements of blood lactate are of value in determining the metabolic

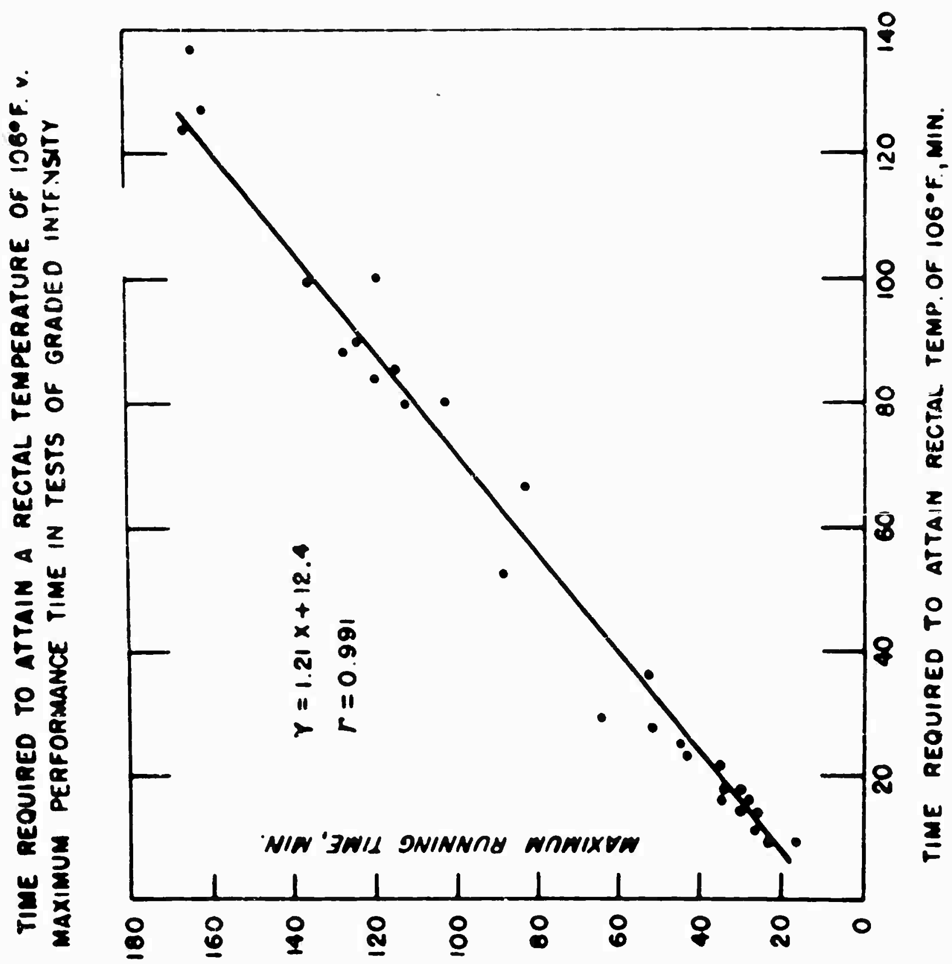

Figure 8. Relationship between the time required to attain a rectal temperature of 106° F. and exhaustive running time in tests of graded intensity.

character of work. Thus, substantial accumulation of lactic acid is evidence of anaerobic work performance. The oxygen debt is used in computing the total work energy expenditure. The absence of excessive accumulation of lactic acid in the blood is evidence for predominantly aerobic work. Little attention is paid to the minor "alactic" debt incurred during this type of testing.

Maximum aerobic capacity and work dehydration: Long-sustained running trials are required to maximize the gross aerobic energy expenditure. In our experimental studies of long-sustained endurance capacity, the total energy expenditure is usually determined from the mean rate of expenditure measured after one and two hours of running, multiplied by the total running time. Reliability of this procedure may be inferred from the following example: During a seven-hour run to exhaustion at 3.63 m.p.h. and 10 degrees of incline, the gross energy expenditure of a 10.37-kg. dog has been computed to be 1332.2 ± 80.6 calories. This estimate is based on 14 measurements of respiratory gas exchange made every 30 minutes during the run. Gross expenditure computed from two measures of gas exchange is 1350.3 calories. It is considered safe to assume that maximum work performance can be adequately determined from the mean of two standard measures of respiratory gas exchange.

For a fixed speed and grade, maximum aerobic energy expenditure is reasonably constant despite variations in body weight and running time. On the basis of 30 long, sustained running trials, the mean gross caloric expenditure is 1193 Calories (standard error of the mean is ±28.2). However, since the rate of caloric expenditure is correlated with body weight ($r = +.899$ [$p < .01$]) as is total running time ($r = -.655$ [$p < .01$]), steps are taken to insure constancy in the weights of the individual dog for any sequence of tests by controlled feeding in order to obviate any unusual bias referrable to changes in body weight.

Two techniques have been utilized to achieve constancy in the rate of work energy expenditure and maximum running time in studies involving restricted nutrient intake and body weight loss. Polyethylene "packs" filled with lead shot are strapped to the animals for added weight. Alternately, the work intensity is controlled by adjusting the treadmill incline. Usually the rates of expenditure are adjusted to the intensities observed during the control phases of testing.

Body weight loss is substantial during exhaustive running. Typically, the dog can lose 9 to 12 percent of the body weight when running to exhaustion. Because of the theoretical interest, computations have been made for water and metabolic substrate loss. The estimates shown below have been made in the course of an exhausting run of 420 minutes duration. Between 30 and 210 minutes of running, the body temperature was constant at 39.1° C.; the respiratory quotient was .79; environmental conditions provided a room temperature of 24.5° C. and a relative humidity of 50 percent. Water metabolism was computed from the constants of Newburgh *et al* (4).

Oxygen uptake, L.		115.620
Carbon dioxide production, L.		91.050
Gross calorie expenditure, Cal.		553.60
Energy source, g.	Fat	42.7
	Glucose	38.2
Water of oxidation, g.	Fat	45.7
	Glucose	22.9

These provide the following stoichiometric relationships:

$$80.9 \text{ Substrate} + 165.1 \text{ g. } O_2 \rightarrow 178.6 \text{ g. } CO_2 + 68.6 \text{ g. } H_2O$$

The estimated components of weight loss are as follows:

Respiratory water lost through humidifying room air, g.	352.3
Tissue lost by combustion of fat and carbohydrate, g.	80.9
[1] Drip loss, g.	146.8
Total g.	580.0

Of the estimated 499.1 g. of water lost, 68.6 g. are theoretically derived from water of oxidation and 430.5 g. are derived from preformed water. While these values are only estimates and necessarily neglect the effects of protein metabolism, they are useful for comparing the extent of work dehydration during various experimental treatments.

Maximum calorie expenditure is related to the extent of work dehydration. On the basis of 43 running tests, the product moment coefficient of correlation between percent weight loss during running and gross energy expenditure is + .869. The regression equation for these functions is $Y = 119.91\ X - 116.40$, where Y is the calorie expenditure, and X is the percent loss in body weight. The standard error of estimate of y on x is 183 calories.

That dehydration is an important factor limiting performance has been demonstrated by supplementation with water during exhaustive treadmill running. *Ad libitum* water intake (1.5 liters) during long, continuously sustained work increases performance capacity by 80 percent ($p < <.01$).

The responses to exhaustive treadmill running of graded work intensity are summarized in Table 2.

Conclusions and Summary

Responses of the dog to the stress of physical work have been presented, and two prediction equations for estimating capacity for work have been discussed. For exhausting work of 10 to 170 minutes duration, running time can be accurately (standard error of estimate is $\pm$ 6.7 minutes) determined from the rate of increase in body temperature. Factors associated with exhaustion in tests of this intensity are elevated body temperature, work dehydration, accumulation of blood lactate, CO_2 blowoff and O_2 debt.

For long, sustained running, maximum energy expenditure may be determined from the body water loss. The prediction equation for these two functions is unfortunately less reliable than the relationship based on increased body temperature. Thus the standard error of estimate for predicting energy expenditure from body water loss is $\pm$ 15.2 percent.

Care must be exercised in selecting appropriate work tests to study physical fitness in the dog in its relationship to diet or other variables. A comprehensive and unbiased approach must take cognizance of the physiologic distortions due to exertion. Relatively short-term running trials may be of value in studying treatment effects when performance is evaluated with respect to body temperature and water loss.

[1] Drip loss which is determined by difference between observed weight loss and the sum of substrate plus respiratory water loss includes in addition to the excess of fluid draining from the oral surfaces, the evaporative loss from the ventral surface of the tongue and water lost through the skin.

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THE MEASUREMENT OF PERFORMANCE IN SMALL LABORATORY ANIMALS

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Evaluation of performance is limited to observations on experimental animals in those circumstances where the experimental variable is a potentially lethal chemical, biological, or environmental agent. We will describe and discuss some methods of measuring performance which have been particularly useful in experimental studies with rodents. Our interest in rodents stems from the hazardous nature of the experimental variable imposed; namely, ionizing radiation, and the desirability of testing large numbers of subjects using species having a relatively homogeneous biological background.

"Performance" may be considered, in general, as behavior in a particular environment. The observed behavior reflects a complex of psychological and physiological factors whose relative importance depends upon the conditions under which the performance is carried out and the interests of the experimenter. For example, the performance may be highly weighted with regard to sensory functions involving discrimination and cognition with little physical effort, or it may involve the outlay of large physical effort wherein sensory and other psychological factors are much less important. Therefore, the test situation created for the evaluation of performance must be clearly defined. This is particularly important for animal studies. All subjects should behave consistently in the test situation and should be equally motivated unless, of course, motivation is under study. The solution to these problems with human subjects is facilitated by their higher degreee of comprehension and the use of verbal instruction. The necessity of conditioning the animal's behavior to assure consistent behavior during testing is readily apparent. The factor of motivation becomes important when the animal is required to sustain a particular level of output which is under examination. The performance may be assayed directly in terms of errors, time, and intensity of effort in a standardized test situation or indirectly by evaluating functional responses which are presumably highly correlated with performance capability. The best estimate of performance in some situations would incorporate both direct and indirect measurements.

We have measured the performance of rodents in (1) a repeated exhaustive swimming exercise test, (2) a motor-driven treadmill, (3) an activity wheel, and (4) a diffuse activity cage. With the exception of studies using motor-driven treadmills, there was very little difficulty in making direct quantitative measurements of performance. These techniques and some of the factors affecting the scores and their interpretation will be described.

Swimming to exhaustion as a forced exercise performance test: Forced exercise studies in intact animals generally involve avoidance stimuli such as electric shock, air blast, or escape from water immersion. The animal is trained to recognize that a particular behavior leads to partial or complete avoidance of the noxious stimulus. The work output may be modulated by altering the difficulty of the task by means of weight loading the animal,

inclining the treadmill belt, or increasing the friction against which the animal must work.

Swimming was selected as a test of performance since it constitutes an intense form of physical effort, and exhaustion is readily discernible. The laboratory rat appears to be highly motivated by water immersion.

In the performance test animals swim individually in 24-gallon cylindrical metal tanks filled with fresh water to a constant level. The tanks are thoroughly cleaned daily and are refilled prior to each day's trials. The water temperature is kept within ± 1.5°C. Food is withhdrawn from the animal approximately four hours prior to testing. The animal is completely immersed in water to remove any residual air trapped in the fur and to reduce buoyancy. The initial time is recorded and the animal swims under continuous observation until he is unable to rise above a line 18 inches below the water surface. When he is below the line for a period estimated to be longer than 15 seconds, the animal is retrieved and the duration of the performance trial is recorded. Any peculiarities in manner of performance are also noted for subsequent evaluation. The use of this criterion is presumed to insure swimming to exhaustion, since the animal at this time shows many signs of marked fatigue such as an inability to maintain normal posture, to walk, or to swim again if returned to the tank immediately following the completion of an exercise trial. Occasionally an animal floats or exhibits other marked abnormalities in swimming behavior and the trial must be discarded.

An experienced technician working with a recording clerk can readily operate ten tests concurrently and run as many as 30 animals in one hour. We have tested rats once daily, with five trials per week, for periods as long as 26 weeks.

The first week's trials are considered as training. During this time the performance may be highly variable. However, by the end of the period performance is stabilized and remains relatively characteristic of each animal's subsequent performance.

Table 1 describes the course of performance during 11 weeks of testing for groups of rats observed in separate experiments. The animals used for each experiment were male members of litters born during the same week from an inbred strain of Sprague-Dawley rats Test animals were selected on the basis of a narrow weight class such that all animals that were used weighed within 10 grams of the group mean (approx. 250 g.). A 10-gram load clipped to the chest fur was used throughout. The load was not changed with time since the repeated swimmming test retarded the increase in body weight to approximately 10 to 15 percent of the initial weight (4) and this effect on load was not considered appreciable.

The principal variables affecting performance time are water temperature and body weight load relationships. Performance time varies with water temperature in such a way that trial duration in 20 to 22°C. water tends to be twice as long as that in 14 to 16°C. water. Without an attached load a 250 g. rat may swim and float in 20°C. water for several hours before the trial is terminated with muscle spasm. The use of a 10-gram load results in performances of 10 to 30 minutes while a 15-gram load will reduce the duration of most trials to less than 10 minutes.

The effects of repeated daily exhaustive swimming exercise upon body

weight and the weights of voluntary muscle (gluteus maximus), heart, kidney, spleen, thymus, adrenal, thyroid, pituitary, and testis have been evaluated in 144 rats sacrificed at intervals during four weeks of daily testing (4). The changes in body weight and most organs with respect to non-exercised controls were related to the number of exercise trials prior to sacrifice. A reduction in body weight with respect to non-exercised controls was accompanied by a reduction in voluntary muscle, kidney, and thymus weight. There was relatively little change detectable in testis and pituitary with repeated exercise. The heart, spleen, thyroid, and adrenals were enlarged after different numbers of exercise trials. The absolute weight of the leg musculature was reduced with exercise although, relative to body weight, the muscle was larger in exercised animals. It is obvious that many of the changes observed utilizing a method of enforced exercise are the combined effects of the non-specific responses to the stress of the test situation and the responses specifically related to the adaptation to exercise. Accommodations to the conditions of exercise are evident in cardiac hypertrophy and, possibly, by a relative although not absolute increase in the size of the muscle participating in the exercise.

Treadmill performance as a forced exercise test: It is difficult to vary markedly the intensity of effort exhibited by the rat in the swimming performance test. For a considerable portion of each test, experienced rats tend to swim frantically regardless of the work load imposed by adding weights. It is well known that the physiological responses to short bursts of intensive muscular effort are considerably different from those involved in a low level of work output sustained over a relatively long period of time. Other methods of performance testing were sought which would permit the investigator to modulate the intensity of effort required of the trained animal in the avoidance response situation.

Either a wire-mesh wheel or an endless belt treadmill, motor-driven at a predetermined speed, appeared to be suitable means of exercising relatively large numbers of rats for extended periods of time. Several versions of the wheel type apparatus were tested, but it was found that when the speed was increased to a rate approximating a rapid walk the animal tended to ride by clinging to the mesh. Further, animals were subjected to considerable trauma when they failed to maintain a running position and tumbled about in the apparatus. Accordingly, the wheel apparatus was abandoned and a belt treadmill was developed for use with rats.

The apparatus consists of a wide endless belt riding on metal rollers. One roller is driven at a selected rate by a variable speed control system. A plywood table between rollers supports the belt so that a flat running surface is provided for the animal. A lucite box, partitioned into 30 individual compartments each 12 inches long, 4 inches wide, and 14 inches high is suspended over the belt providing a limited area in which each animal may exercise (Fig. 1). A shock grid (540 volts, 0.8ma) passes through the rear of each compartment. The animal's tail is taped to a wire suspended from the top of the compartment to prevent the tail from being caught under the rear wall by the moving belt.

The animal is trained to avoid the electric shock by keeping pace with the belt movement. After preliminary training consisting of five trials it is only necessary to activate the shock grid intermittently and the animal will continue to run until nearly exhausted. Painting the posterior portion of the

side walls offers the animal a visual cue as to the area containing the shock grid.

Direct determination of the time for complete exhaustion is extremely difficult because of the variability in behavior which occurs as the rat becomes exhausted. Some animals will slide into the shock electrodes for increasingly longer periods of time while others will turn about and attack the electrodes. Although the shock intensity is light to the observer's touch there is always the problem of an animal injuring himself through his manipulations at the grid end of the moving belt if allowed to remain there for long periods.

Despite these difficulties it is still feasible to describe the duration of performance possible in a specified population of rats as a function of the belt speed. To this end adult male Sprague-Dawley rats, 72 ± 3 days of age, were trained to run on the treadmill once daily, five times per week, for four weeks. Each trial was terminated when the animal lay against the electrodes and refused to exercise further when replaced in a running position on the treadmill.

The data are summarized in terms of the average duration of the longest daily trial accomplished per week at each speed (Table 2). During the first week of exercise some of the animals were adapted to the belt operated at a low running speed which was gradually increased during the first five trials. This procedure facilitated the adaptation of animals to the treadmill but did not confer any significant advantage in terms of subsequent performance time. At rates of 30, 40, and 60 feet/minute repeated exercise resulted in an increase in performance. At the lowest speed (30 feet/min.) a rat can exercise 17 hours. The time to exhaustion at 40 feet/minute was 25 percent shorter than at 30 feet/minute, although the distance traveled was nearly identical. At 80 feet/minute the limit of physical capacity under these conditions was approached and further exercise experience did not improve the situation in terms of the attainable length of running.

Some further evaluation of performance was obtained by studying body weight changes during the course of four weeks of exercise, heart rate, and colonic temperature. When animal groups were exercised for either two, four, or eight hours per day at 40 feet/minute the effects upon body weight were transient. There was an initial decrease in weight which was related in degree to the duration of the daily exercise trial. The rate of growth was comparable to sham-exercised controls. Heart rate, during 30 minutes to six hours of continuous exercise at speeds of 37 to 75 feet/min., increased rapidly with the onset of exercise to a peak value approximately 25 percent above the initial rate. The heart rate remained elevated for approximately one hour, then decreased gradually to near-resting values if the exercise was continued. If the duration of exercise was less than an hour the heart rate fell rapidly with cessation of exercise, reaching resting values within a few minutes. Colonic temperature during 30 minutes of exercise at 50 feet/minute increased approximately 2.2° F. during the first 10 minutes and remained elevated during the remainder of the exercise period. Upon completion of the task, temperature fell gradually to resting levels within one hour. These findings suggest that treadmill exercise under the conditions described was of moderate intensity for the rat and was well tolerated. This concept is corroborated by the findings that daily exhaustive swimming exercise markedly increases the lethality response to ionizing radiation,

whereas daily treadmill exercise of durations up to eight hours at 40 feet/minute does not.

Activity measurements: Physical activity which is not explicable in terms of specific external stimuli is generally considered an expression of physiological state and is used under certain circumstances (3) as an index of malaise of the organism. Activity is a performance measure which can be quantitated readily in the small laboratory animal. The factors which influence activity performance are many and have been intensively studied by investigators in diverse fields. Their findings have been reviewed by Shirley (8), Reed (7) and Munn (6). There appear to be four major groups of variables affecting the pattern of activity observed. These are: (1) the type of apparatus used, (2) the test environment (illumination, temperature, extraneous stimuli), (3) the test procedure employed (duration of measurement interval, diet, manipulations of the test animal) and (4) constitution of the test animal (sex, age, genetics, physiological and psychological state). We propose to describe two methods of activity measurements which have been used successfully to assay changes in physical activity following exposure to ionizing radiation. The two methods differ primarily in the types of apparatus employed. Physical activity measured by the wheel cage method will be described as volitional activity*, whereas activity measured in spring-suspended cages will be described as diffuse activity.

**Volitional activity*: The apparatus consists of a vertically revolving wheel, 4½ inches wide and 14 inches in diameter (Fig. 2). Each wheel is equipped with a Veeder-type counter which records revolutions of the wheel in both directions. Food and water are always available in a small living cage which is connected with the wheel proper through an access port. Each wheel cage apparatus is placed in a sound-deadened box which is open at the front. The living cage faces the open side of the box to provide maximum isolation of the wheel. Up to 12 such boxes are placed in each of ten sound-proofed rooms in an air-conditioned building. All sound insulation is accomplished through the use of 1¼-inch acousti-celotex linings. Each of the rooms is illuminated constantly by a single 150-watt incandescent bulb, and each is supplied with its own air exchange system.

For each experiment, wheel readings are taken once daily at the same time in order to minimize disturbing the animals. Feeding and watering is accomplished at reading time once a week, and cleaning at the same time on alternate weeks. The animals are not otherwise disturbed except for special experimental treatment, if applicable. Prior to each series of studies, wheels are calibrated, using the system recommended by Lacey (5). It has been found that all wheels have similar moments of inertia, and that in no case is it necessary for a young adult animal to move more than 0.4 cm along the wheel in order to overcome friction. All animals were maintained on a diet of Purina Laboratory Chow which is ground to a meal in order to prevent jamming of the wheel cage by food pellets. Animals are never transferred from one cage to another during a study, and cages are thoroughly washed between experiments. In this way, it is possible to consider the animal and the apparatus as a single unit, subject to minimal variations with respect to the environment. Male rats of the Sprague-Dawley strain, bred in the Laboratory colony, are used and are accommodated to constant light in individual cages for at least two weeks prior to entry into the wheel cages. Animals not exhibiting normal growth patterns during this period are discarded.

*This term may be interpreted to mean "periodical running."

Only male rats are used since females show cyclical patterns of activity which are very precisely correlated with stages of the estrus cycle. The effect of age and experience in the apparatus are illustrated in Fig. 3. Although daily readings were taken, the data are summarized as the mean revolutions per 24 hours for each week. The weekly 24-hour mean for each group is based on $7n$ observations, where n is the number of animals in the group observed seven times per week. The value for the third week in the 72-day group is influenced by the fact that these animals were confined within plastic boxes on Monday of that week for sham irradiation since this group served as a control for an irradiation series.

It is apparent that the activity level of rats is influenced by age as well as experience in the wheel. At any given time, the younger the initial age of the group, the greater is the activity. The activity time curves are not parallel, with the exception of the two older groups, indicating that there is an interaction between age and experience which has less effect as the animal grows older. Details of the age-experience-activity relationships have been published elsewhere (2).

The consistency of the wheel cage method in measuring volitional activity was determined by correlation coefficients summarized in Table 3. The correlation coefficients indicate that the method is considered to be reliable. The degree of variability also appears to be a function of age and experience in the wheel.

Extension of volitional activity studies to species other than the rat has been attempted. The existing apparatus proved to be unsatisfactory for the guinea pig since this species does not utilize the wheel. The adult male hamster is eminently suited for wheel activity performance. Whereas the 72-day old rat will run 0.3-0.5 miles per 24 hours the hamster will run 10 to 15 miles per 24 hours. The general trend of hamster activity with time in the wheel appears to be a continuous decline in volitional activity. Mean daily values are in the order of 17,000 revolutions during the first 24 hours in the wheel. Activity decreases rapidly during the first week, then more gradually during subsequent weeks to approximately 7,000 revolutions after 4 to 6 weeks. Some comparative aspects of volitional activity of rat and hamster, with increasing experience in the wheel, are tabulated below for typical patterns:

Volitional Activity (Revolution/Day)	Rat	Hamster
Day 1	100	17,000
7	500	11,000
25	700	9,000
42	500	7,000
Time of Maximum Activity:	3-4 weeks	Day 1

Diffuse activity: A variety of instruments has been used to measure the diffuse activity of animals. These include tambour and spring-suspended cages or chambers equipped with photocel-activated counters, electrical grid contact counters, kymographic recorders, radio signal detectors, and elec-

tronic integrator units. Long-term measurements of activity require a cage-recording system which would (1) be reasonably sensitive yet stable enough for long-term usage, (2) require minimum maintenance with respect to mechanical adjustments and food and water replenishment in order to avoid undue disturbances to the animal, and (3) provide information concerning activity in an integrated, readily usable form in order to facilitate data analysis. In addition, a method of calibration appears essential in order to determine the stability of the unit with prolonged use. Unfortunately, most instruments described in the literature failed adequately to meet these criteria. A mechanical apparatus for the measurement of diffuse activity of small animals was developed consisting of a spring-suspended, stabilized cage and an integrator, made of clock parts, which yields a cumulative numerical index of the animal's activity (Fig.2). The cage is triangular in shape and made of aluminum with a wire mesh bottom. Each cage is suspended by a coil spring and stabilized with two flat springs along one side. The recording mechanism is activated by downward excursions of the cage and the values recorded in terms of dial units. Details of it fabrication and calibration are published elsewhere (1). The apparatus has been found to be stable in its response despite marked changes in load mass and location of mass within the cage. Rank order correlations of 24-hour activity values of rats have demonstrated the units to be reliable for the test over a ten-week period of continuous use. Forty-five of these units are located in a continuously illuminated, sound-damped room equipped with an air exchange system and thermostatically controlled heating system.

Diffuse activity performance has been studied in male hamsters, rats, and guinea pigs. Prior to entrance into the activity cages the animals are maintained on appropriate diets under conditions of continuous light for several weeks. Records of activity are obtained daily while food is supplied and refuse papers changed at weekly intervals. Water is supplied *ad lib* by means of an automatic watering system.

It should be recognized that the reading obtained in diffuse activity measurements is the integrated value for downward displacement of the cage per 24-hour interval and is not simply the number of excursions. Because of their body weight, guinea pigs will exhibit very high scores, whereas hamsters will have low scores. Evaluation of activity performance is normally restricted to comparisons within a species.

The diffuse activity pattern has been found to be characteristic of a given species. Over 45 consecutive days of measurement, the diffuse activity of rats increased rapidly from an initial value of approximately 1600 units/24 hours to a level of 2000-2700 units/24 hours by the second week and remained at that level. The activity of hamsters began at 250 units/24 hours and fluctuated between 350-450 units/24 hours after the second week. Activity of the guinea pig increased from an initial level of 2000 units/24 hours to approximately 5000 by the end of the second week. Activity in this species appeared to level off between 7000-8000 units/24 hours.

It is readily apparent that the pattern of activity performance obtained is highly dependent upon the test apparatus employed and presumably reflects somewhat different parameters of function. The diffuse activity of rats remains relatively constant with time, while volitional activity for the same age increases for approximately three weeks and then progressively decreases with time in the wheel. Volitional activity performance has both experience and age components, while there is no experience effect observ-

able with diffuse activity after the first few weeks. Wheel cages of the dimensions described proved to be unsatisfactory for volitional activity measurements of guinea pigs because this species did not make use of the wheel. However, diffuse activity scores could be obtained routinely. The volitional activity performance of hamsters was remarkably high initially and declined with age and time in the wheel, whereas the diffuse activity pattern of hamsters remained relatively constant with time.

In summary, we have described some techniques which have been useful in providing direct measurements of performance in rodents. It is possible to evaluate directly the effect of an experimental treatment upon the performance of an enforced, intensive exercise as well as upon voluntary and diffuse physical activity performance. Data concerning the performance of normal subjects were described for each test situation. It is difficult to establish reliable criteria of exhaustion for rats in treadmill exercise situations even though the animals are highly conditioned by shock avoidance to run on the treadmill. The use of the treadmill can presumably lead to an expression of fitness for rodents by establishing the effect of an experimental treatment upon functional responses to a specified treadmill task.

TABLE 1.

BASE TIMES AND WEEKLY PERFORMANCE IN PERCENT OF BASE TIME, IN MINUTES, FOR ANIMALS EXERCISED DAILY FIVE TIMES PER WEEK FOR FOUR WEEKS OR MORE. EACH GROUP CONSTITUTES THE CONTROL ANIMALS FROM EXPERIMENTS MADE OVER A 12-MONTH PERIOD.

	Exercised Group A	Exercised Group B	Exercised Group C	Exercised Group D
No. of Animals:	19	7	25	33
Mean Base Time, Min., ± S.D.:	16 ± 3	20 ± 3	19 ± 2	16 ± 3

Weekly mean performance in percent of base time (mean for 5 trials of 2nd week)

Weeks of daily exhaustive swimming exercise	Group A	Group B	Group C	Group D
1	96	83	91	79
2	100	100	100	100
3	95	97	99	105
4	96	106	111	110
5	100	114	117	
6	107	104	121	
7	109	115	119	
8	107	118	119	
9	104	111		
10	107	115		
11	114	116		

TABLE 2.

THE AVERAGE DURATION OF THE LONGEST TRIAL, IN A GIVEN WEEK, ACCOMPLISHED BY RATS REQUIRED TO RUN ON THE TREADMILL FIVE TIMES PER WEEK. DATA HAVE BEEN ROUNDED OFF TO THE NEAREST QUARTER HOUR.

Experience	Belt speed ft/min	No. of animals	Average duration of the longest daily trial for each week (hours)				Distance of the 4th week trial (feet)
			Week 1	Week 2	Week 3	Week 4	
Untrained	30	11	5¾	10¾	15½	17	30,600
	40	5	1¼	6¾	10½	12¾	30,600
	60	6	1¼	2	2	2¾	9,900
	80	6	¾	½	½	¾	3,600
	100	4		Cannot tolerate	this speed		
Trained	40	3	Training	7¼	10½	13	31,200
	60	5	"	1¾	2	2¾	9,900
	80	6	"	¾	¾	¾	3,600
	100	5		Cannot tolerate	this speed		
Combined	30	11	5¾*	10¾	15½	17	30,600
	40	8	1¼*	7	10½	13	31,200
	60	11	1¼*	2	2	2¾	9,900
	80	12	¾*	¾	¾	¾	3,600
	100	9		Cannot tolerate	this speed		

* Excluding training period

"Trained" animals were adapted to the treadmill at a low speed which was increased with successive trials until the final constant speed noted in the table was reached. Training was limited to the five trials of the first week. "Untrained" animals were forced to exercise at the final speed from the first trial.

TABLE 3.

COEFFICIENTS OF RANK ORDER CORRELATION FOR VOLITIONAL ACTIVITY MEASURED ON SUCCESSIVE MONDAYS IN NORMAL MALE RATS OF DIFFERENT AGES.

Age Group, Days	No. of Animals	Consecutive Mondays Compared					
		1-2	2-3	3-4	4-5	5-6	6-7
51	25	0.44	0.79	0.90	0.82	0.75	0.69
72	15	0.72	0.43	0.62	0.85	0.92	0.80
100	15	0.70	0.69	0.76	0.79	0.90	0.83
142	17	0.18	0.61	0.78	0.86	0.88	0.81
212	17	0.39	0.90	0.95	0.89	0.96	0.94

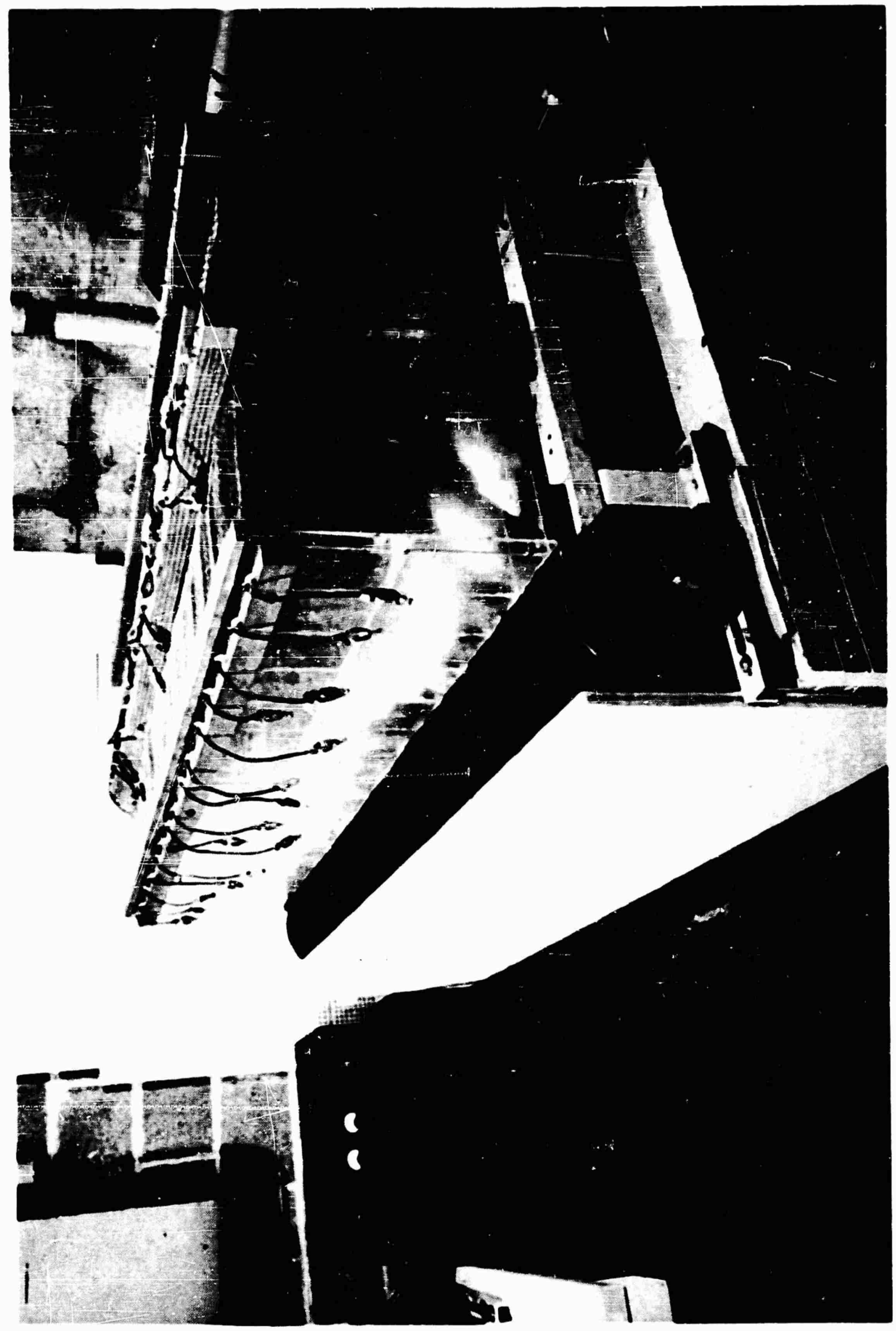

Fig. 1. Thirty-unit motor-driven continuous belt treadmill used with electric-shock conditioned rats. Tails are taped to a wire overhead to prevent trauma. The treadmill can be tilted to a specified angle.

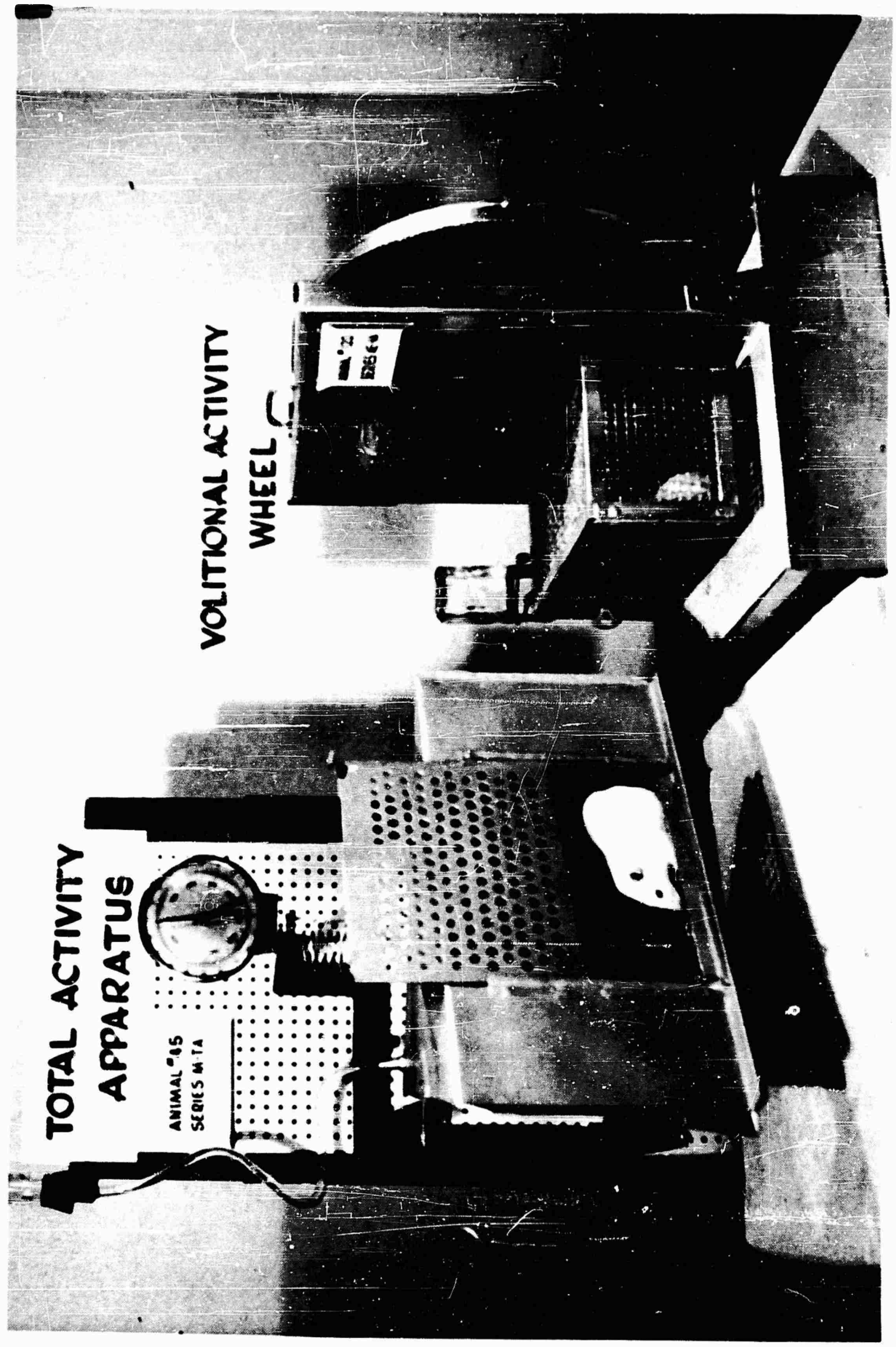

Fig. 2. Total (diffuse) activity and volitional activity apparatus used to measure physical activity performance in small animals.

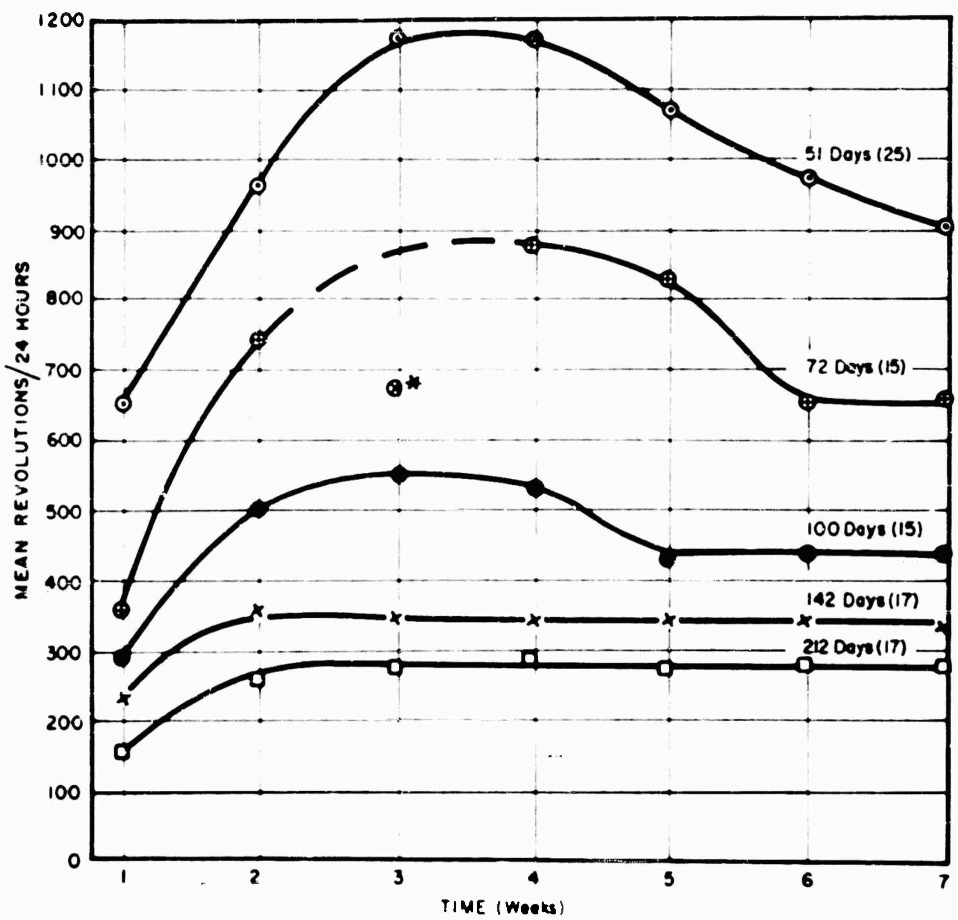

Fig. 3. Volitional activity curves for normal male rats of different ages observed for seven weeks. (Asterisk indicates that this group was sham-irradiated on Monday of the third week as a control for an irradiation experiment.) From *Am. J. Physiol.*, *172*, 109 (1953) (2).

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WORK TESTS IN ANIMAL STUDIES

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The same Work Capacity Test on the treadmill as described earlier in man was employed in animal studies. Work capacity of dogs was determined before and after lung resection and before, during, and after acclimatization to low barometric pressure. The animals were trained for running on the treadmill and had a surgical operation for the construction of a Van Leersum carotid loop. A special device, fitted around this loop, permitted the measuring of pulse rate and blood pressure as in the human experiments. For measuring the respiratory gas exchange, the dogs were fitted with special rubber masks.

The experiments revealed that the test criteria used in the human experiments were likewise reliable indicators of the work capacity of dogs. Variations observed in the test results and in the cardiovascular-respiratory response pattern reflected the experimental conditions as tests were performed (a) on ambient air or in acute hypoxia before and after altitude acclimatization, and (b) shortly or at some later date after lung resection, with and without physical training during the phase of recuperation.

Although the human subject is preferable to animals in work capacity studies because of many methodical and technical advantages, some gaps in our knowledge have to be closed by animal experimentation. In our studies on altitude-acclimatized man and dog the circulatory-respiratory adaptations to the gradually increased work were similar. The studies on the effect of physical training upon the recovery of lobectomized dogs certainly suggested the desirability of a similar rehabilitation therapy in man. The effects of vigorous training on capillary growth, glycogen storage, etc., can only be explored through studies on animals. Eventual studies on man have to be preceded by animal experimentation as, for instance, in hypothermia. If the problems to be investigated are properly selected, the results gained from such animal work should correlate well with work on man.

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STANDARD WORK TESTS IN MAN: Some Illustrative Results

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Harvard Fitness Test (*Treadmill Version*). The results of the tests to be discussed here were obtained on groups of 10 to 15 men during the course of a specific stress situation such as dehydration and semi-starvation. In most instances, the experimental regimen was in effect for more than one week, and periodic testing was carried out. When an assessment of deterioration in ability to perform physical work is made in this type of experiment, the investigator-equipment time complex becomes rather important. This complex imposes limits on the information-gathering potential during the course of the experiment if either equipment or numbers of investigative personnel are limited. Thus, simple, rapid determinations are frequently those of choice. If four men must walk on the treadmill at one time and several groups of four must be measured in one day, it would be difficult to monitor pulse rate, ventilation volume, blood pressure, etc., continuously for all men without considerable instrumentation and/or a larg investigative force.

The above is common knowledge to most of us; however, we cannot lose sight of the fact that the over-all scope of the experiment frequently limits the number and type of work performance measurements that can realistically be utilized. The preceding comments are not made with the view that the test battery we have used is necessarily the best.

The first test to be discussed is the treadmill version of the Harvard Fitness Test. The working conditions are 7 mph, 8.6 percent grade; the subject runs as long as he thinks he can or to a maximum of five minutes. Scoring of the test is as follows:

Score $=$ 100 x Seconds Run $/ 2\ \Sigma P$, where $\Sigma P =$ thh sum of heart beats counted from 1.0 to 1.5, 2.0 to 2.5, and 4.0 to 4.5 minutes of recovery.

The score is directly proportional to the duration of running and inversely proportional to the recovery pulse rate. Both work capacity and motivation contribute to the final result.

The experience of the Minnesota group with this test is summarized below. Table 1 shows the results obtained in the 24-week semi-starvation study carried out in 1944-45 with conscientious objectors as subjects. Note that both running time and score were drastically reduced by 24 weeks of diet restriction, and all men were rated *poor*. These results, and the results of other tests, led the investigators to the conclusion that a severe deterioration in work capacity had occurred. They were, no doubt, right in this instance.

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If we pass now to the 1953 diet restriction experiment (580 kcal/man/day), in which soldiers served as subjects, (figures 1a and 1b), we see that the test score tends to improve with time, and little over-all change in running time occurred. At approximately day 15 (the 6th day of semi-starvation) a decrement in running time and score occurred. Please keep these observations in mind when you look at figures 2a and 2b. The running time and scores for the 1954 semi-starvation experiment are shown in figures 2a and 2b. Again, as in 1953, we see an over-all improvement over days in the score and also an over-all improvement in running time.

TABLE 1.

EVALUATION OF PERFORMANCE USING THE TREADMILL VERSION OF THE HARVARD FITNESS TEST

Conditions for running: 7 mph, 8.6 percent grade
(Diet — 1550 kcal/day)

	Control	Starvation 12 weeks	Starvation 24 weeks
Time of run in seconds	242	106	50
Score	64	33	18
Score evaluation:			
Good	12	0	0
Average	17	7	0
Poor	3	25	32

Further, the decided fluctuations in both curves should be noted. In each instance of a distinct low or a peak, it was felt by the investigators that known psychological factors were influencing the running time or score, e.g., the appearance of an inspection team (high values), apprehension concerning ability to withstand the caloric restriction (low values), etc. In at least one instance, results of professional psychiatric examination corresponded with the results obtained with the Harvard Fitness Test. While the motivational component probably did not contribute to the results obtained in the 24-week study, it definitely *was* a factor in the 1953 and 1954 experiments. These findings suggest that an evaluation of work capacity from Harvard Fitness results is complex, and care must be taken to minimize or to control the motivational component. On the other hand, the test may well serve as an indication of "motivational climate" during the course of an extended study and contribute valuable information on this aspect of work capacity that would be hard to obtain in any other way.

Two other observations are also of some consequence, if the Harvard Fitness Test is considered for use during the course of a long-term experiment. Changes in physical fitness may be induced by frequent performance of the test or other physical activities. Changes may also occur in cardiovascular function as a direct result of the stress, e.g., bradycardia with semi-starvation. We have seen that a combination of these factors can lead to fallaciously high scores, scores that one would expect only well-trained athletes to achieve.

One further consideration deserves emphasis in a discussion of the Harvard Fitness Test. Several investigators have decided to avoid the diffi-

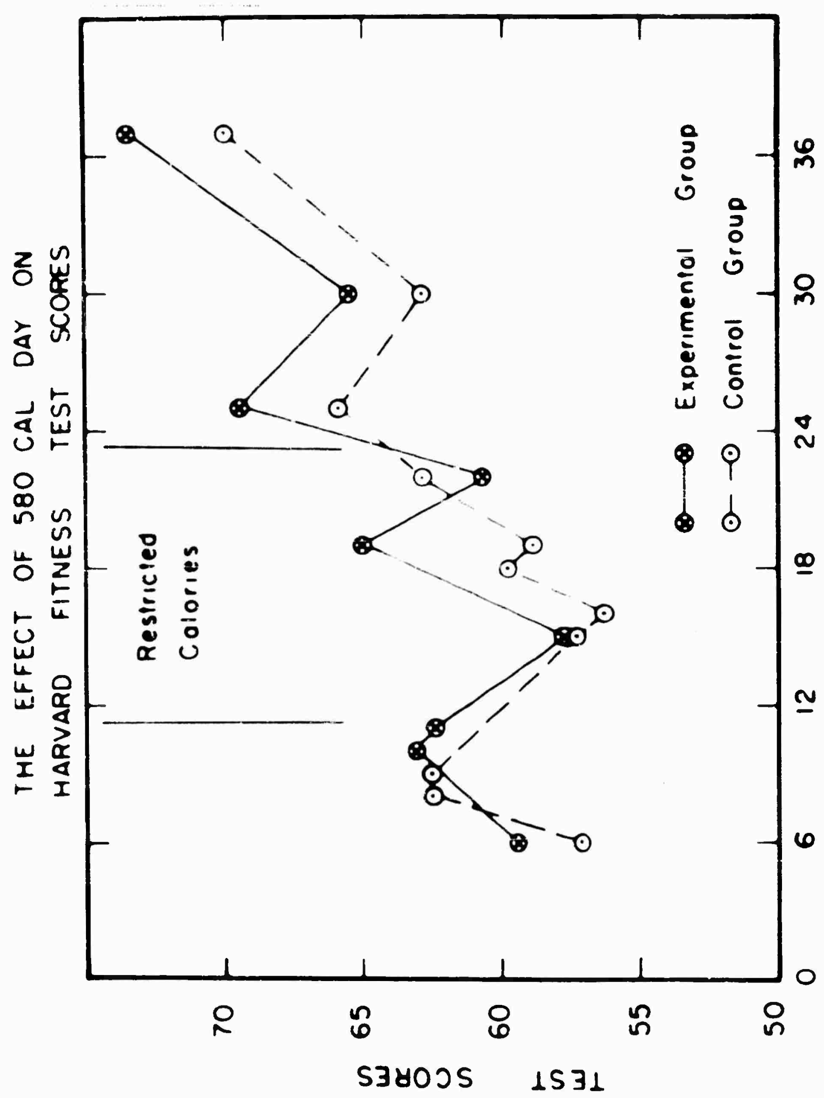

Figure 1a. The effect of 580 Cal/day on Harvard Fitness Test Scores. Control group received calories *ad lib* and experimental group received 580 Cal/man/day.

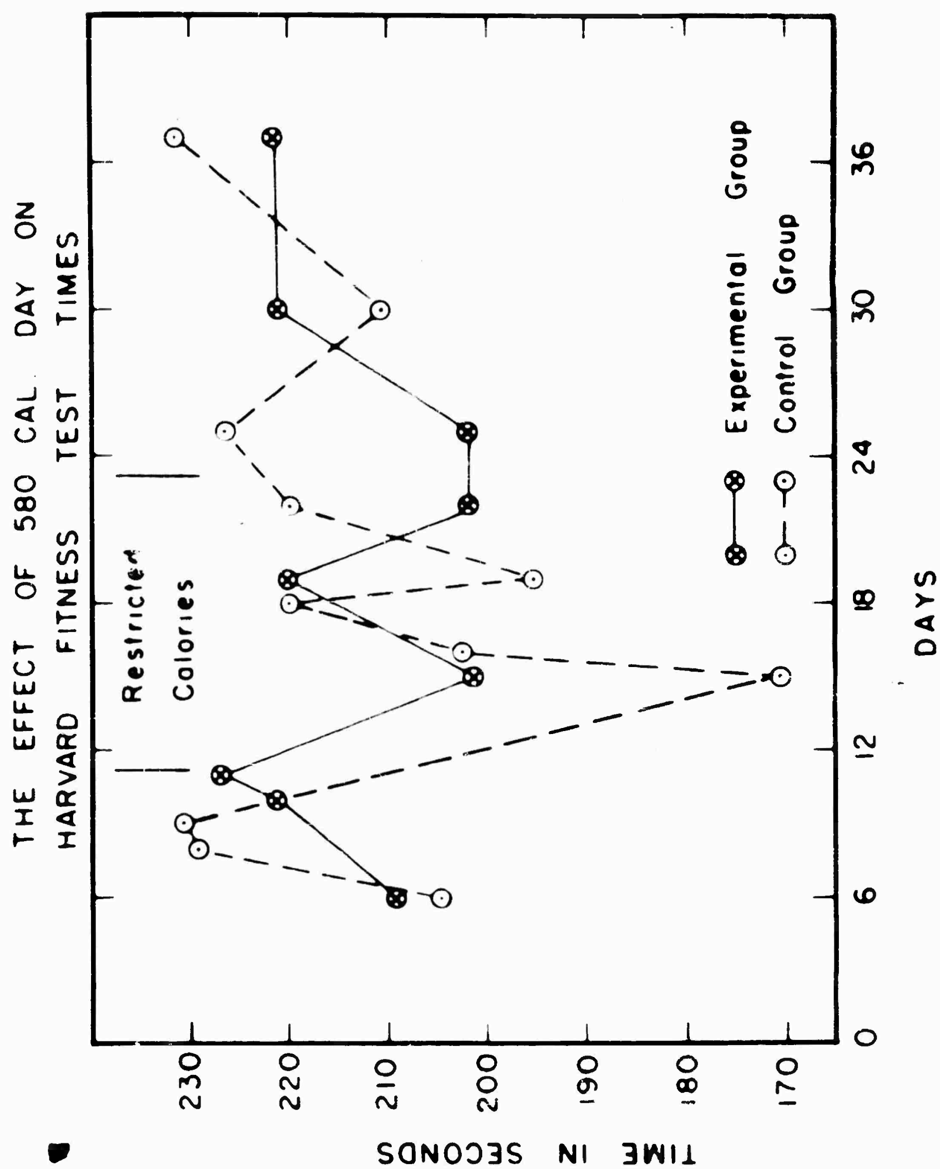

Figure 1b. The effect of 580 Cal/day on Harvard Fitness Test Times. Control group received calories *ad lib* and experimental group received 580 Cal/man/day.

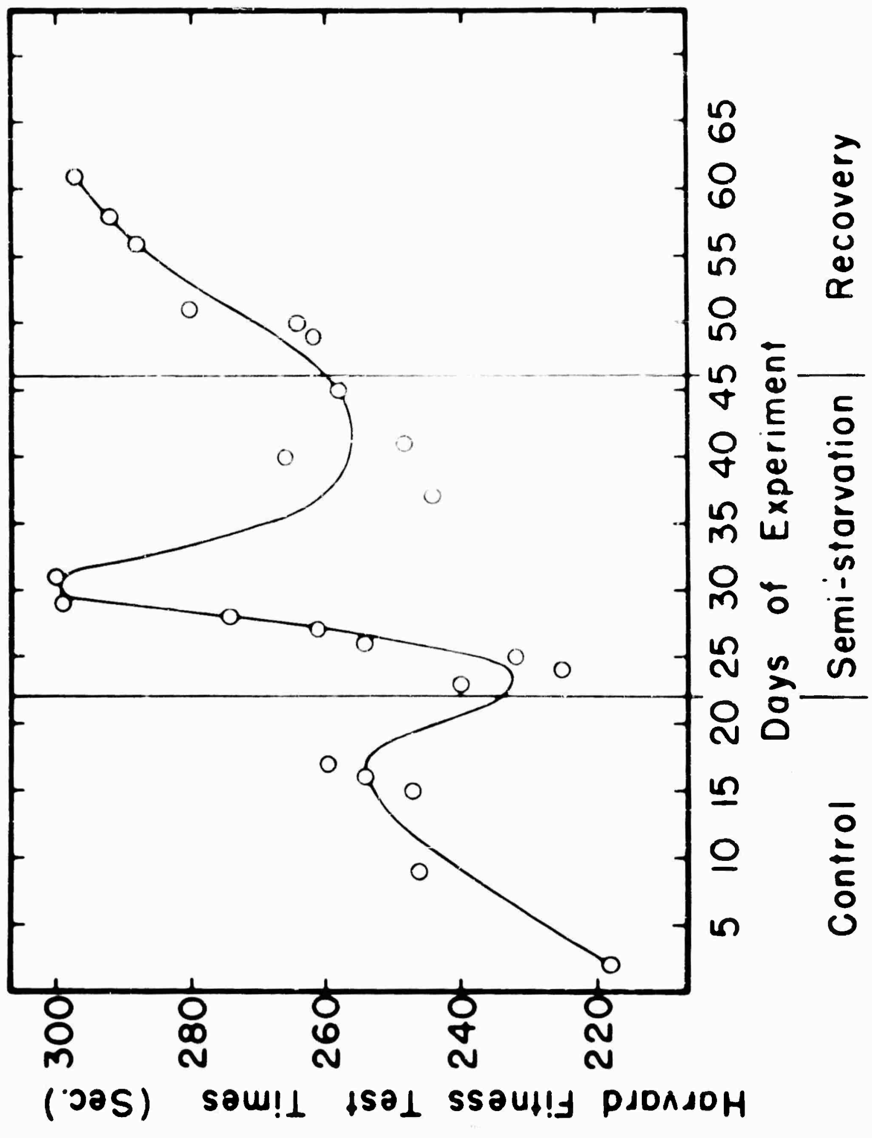

Figure 2a. The effect of 1010 Cal/man/day on Harvard Fitness Test Times.

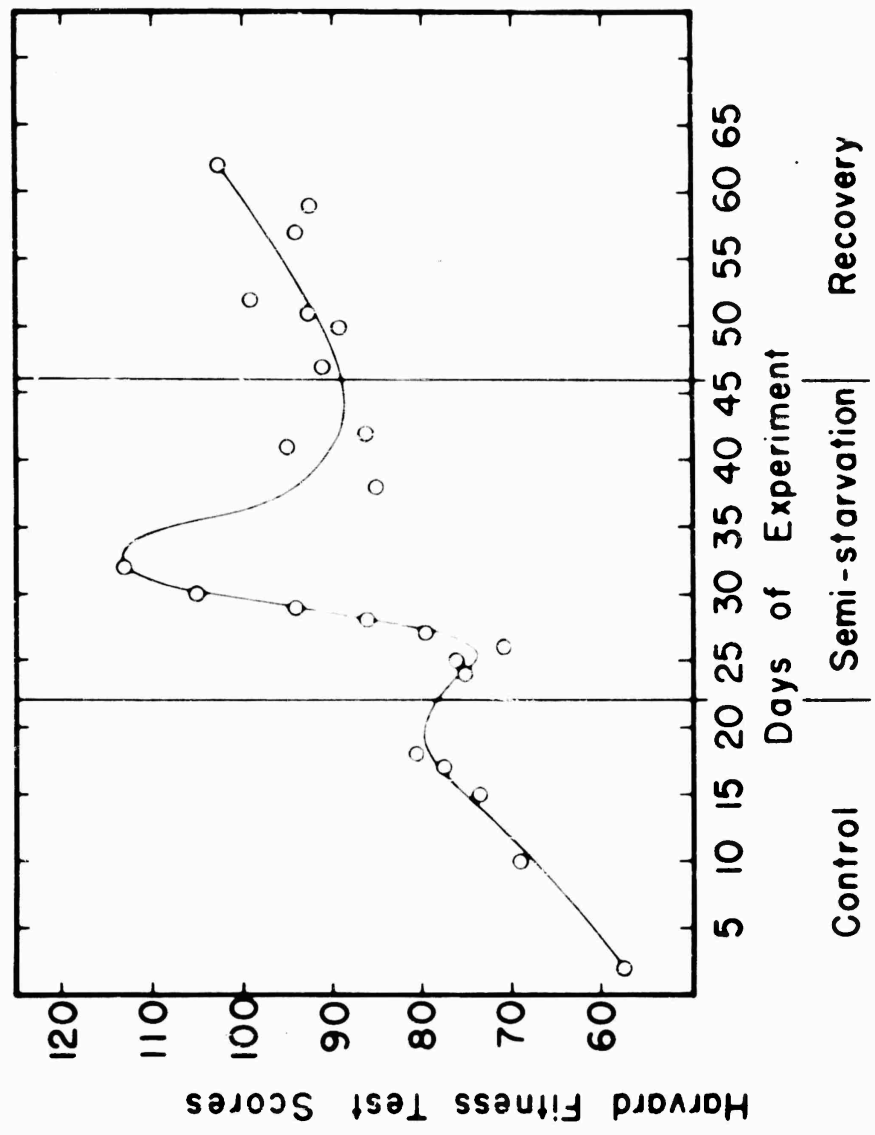

Figure 2b. The effect of 1010 Cal/man/day on Harvard Fitness Test Scores.

culty of controlling or assessing motivation and have used the test as a fixed work task with a stepping or running time of three minutes. Most individuals can perform the test for three minutes, and one is left with essentially a test of cardiovascular function, specifically, recovery heart rate. This raises the question — why not use the recovery heart information *per se* and forget about calculating a performance score?

Inspection of figure 3 will reveal why this question is asked. Figure 3 shows the weight change and the change in the sum of the recovery pulse rates after running during the course of the 1954 semi-starvation experiment. The results of two men are shown; both men ran the full five minutes each day they were tested. A decrease in recovery pulse rate occurred during the control period (food and H_2O *ad lib*) and a further over-all drop occurred during the caloric restriction period. These decreases may well be associated with physical conditioning in the control period and general semi-starvation bradycardia, together with the reduced workload in the restriction period. The point is that a score calculated from this data would indicate a decided improvement in the control period and a further improvement in the restriction period. The further improvement in the restriction period is open to question. Thus, a plot of only the Harvard Fitness Test Score would be misleading, while a plot of the recovery pulse rate provides useful information.

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Maximal Oxygen Intake. The next test to be presented is the so-called "maximal oxygen intake" test. Actually the term "maximal oxygen intake" is misleading, because "maximal" can only refer to that value of oxygen intake achieved under the specified experimental conditions. One obtains a different answer, for example, if the subject warms up prior to running in a cool environment, performs grade walking instead of grade running, performs arm work in addition to running, etc. Many pre-test regimens will influence a "true" maximal oxygen for running, but these treatments can be standardized and/or controlled with the proper experimental design.

The basis for the test was the classical work of Hill who demonstrated the following: there is an upper limit to the capacity of the combined respiratory cardiovascular system to transport oxygen to the working muscles; there is a linear relationship between oxygen intake and workload until the maximal oxygen intake is reached; further increases in workload result in an increase in oxygen debt and a shortening of the time work can be performed.

The test procedure consists of grade running at 7 mph on the treadmill for three minutes. A starting grade is established from subjective evaluation of the subject's performance of the Harvard Fitness Test (treadmill version).

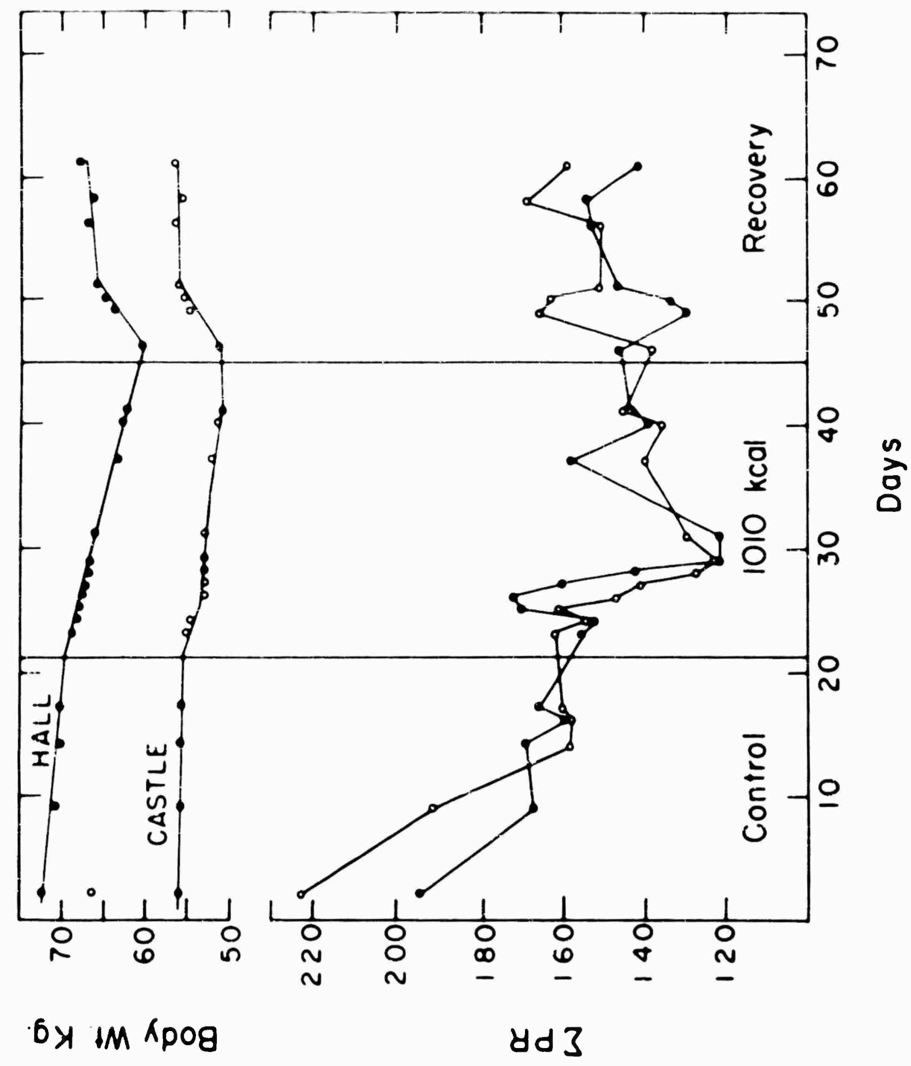

Figure 3. The effect in two men of 1010 Cal/man/day on morning body weight (Wt.) and sum of recover pulse rates (ΣPR) after running. Each man five minutes per day at 7 mph, 8.6% grade.

The subjects are asked to run each day for a minimum of three days and occasionally for as many as five days to establish the grade that will produce a "maximal oxygen intake." With each successive run the grade is increased by 2.5 percent. Expired air is collected between 1 min. 45 sec. to 2 min. 45 sec. of each run, and the oxygen consumption is calculated.

Although recent technological advances (respiratory flowmeters, O_2 and CO_2 analyzers, etc.) would permit continuous measurement of oxygen consumption, an advantage if a picture of the dynamic shift in oxygen consumption is desired, the fixed-interval sampling procedure has proven adequate for our purposes. Both Robinson's and our information indicate that the sample of expired air taken between 1'45" to 2'45" represents the plateau of oxygen intake usually achieved after 1'30" of running. (See Figure 4.)

Figure 5 shows the results of this procedure in four separate subjects. In each instance, a break in the oxygen consumption curve is apparent. This point is termed the level of maximal oxygen intake. In practice the following criterion was used to recognize the maximal oxygen intake: If two consecutive measurements separated by a grade of 2.5 percent differed by less than 150 cc/min or 2.1 cc/kg/min, a "maximal oxygen intake" was said to have been reached.

The test has worked well in practice since it is relatively easy to administer, is independent of motivation, requires little in the way of expensive specialized laboratory equipment, and is amenable to long-term studies where the test subjects reside in the laboratory for several weeks at a time. Most men can run 7 mph for three minutes and the average subject can adjust to changes in grade more readily than changes in speed.

Table 2 is presented to support the view that the maximal oxygen intake is reasonably sensitive to changes induced by a number of stress situations. We see that substantial decreases were observed with bed rest, malaria, and extended semi-starvation, while more moderate decreases were observed with a short period of acute starvation and a 12-day period on minimum calories. Acute dehydration also produced a decrement in the maximal oxygen intake (Table 3).

TABLE 2.

EFFECT OF VARIOUS BIOLOGICAL STRESSES ON THE MAXIMAL OXYGEN INTAKE

Condition Observed	Duration of Stress (Days)	$\dot{V}_{O_2}$ 1/min Control	Post Stress	Decrease	Percent Decrease
Bed Rest	21	3.85	3.18	0.67	17.4
Malaria	10	3.69	2.95	0.75	20.1
Acute Starvation	4.5	3.45	3.19	0.26	7.5
Minimum Calories*	12	3.46	3.32	0.14	4.1
Semi-Starvation**	180	3.11	1.95	1.16	37.3

*580 kcal/day
**1600 kcal/day

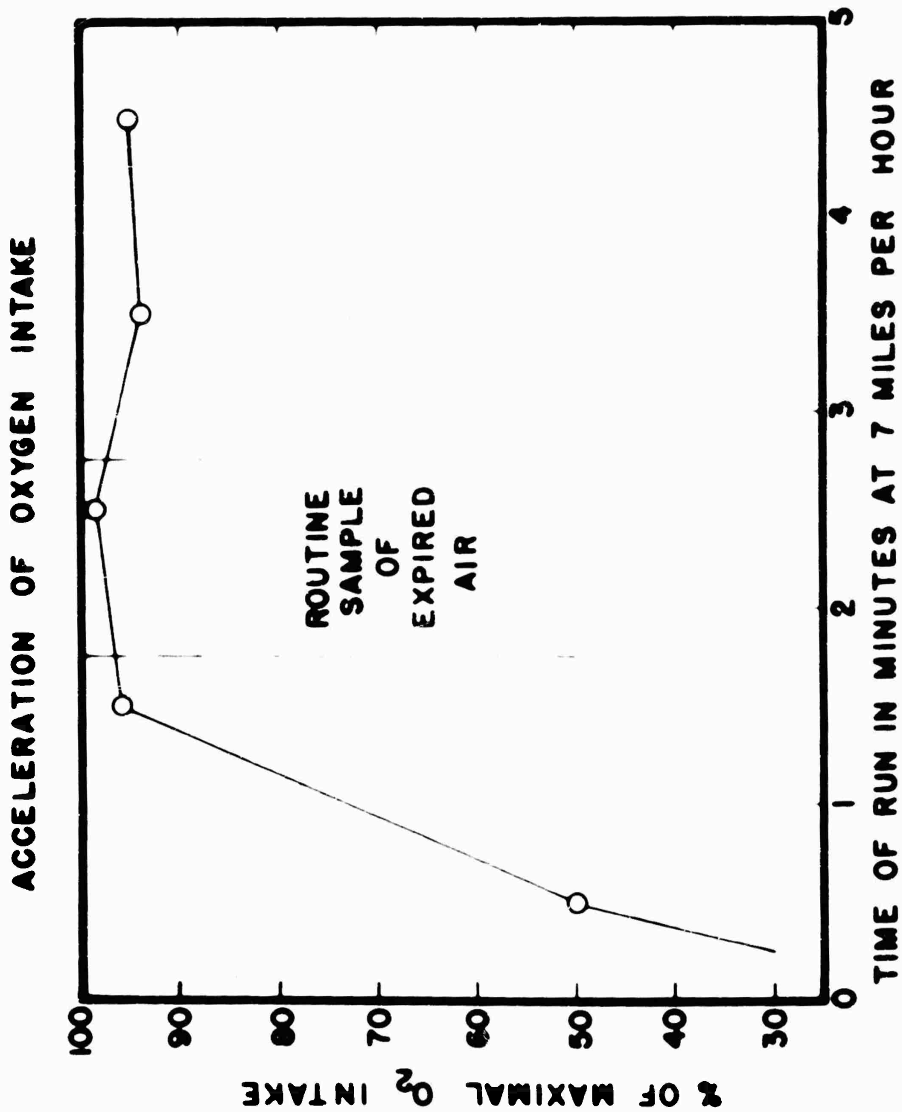

Figure 4. Acceleration of oxygen intake during running.

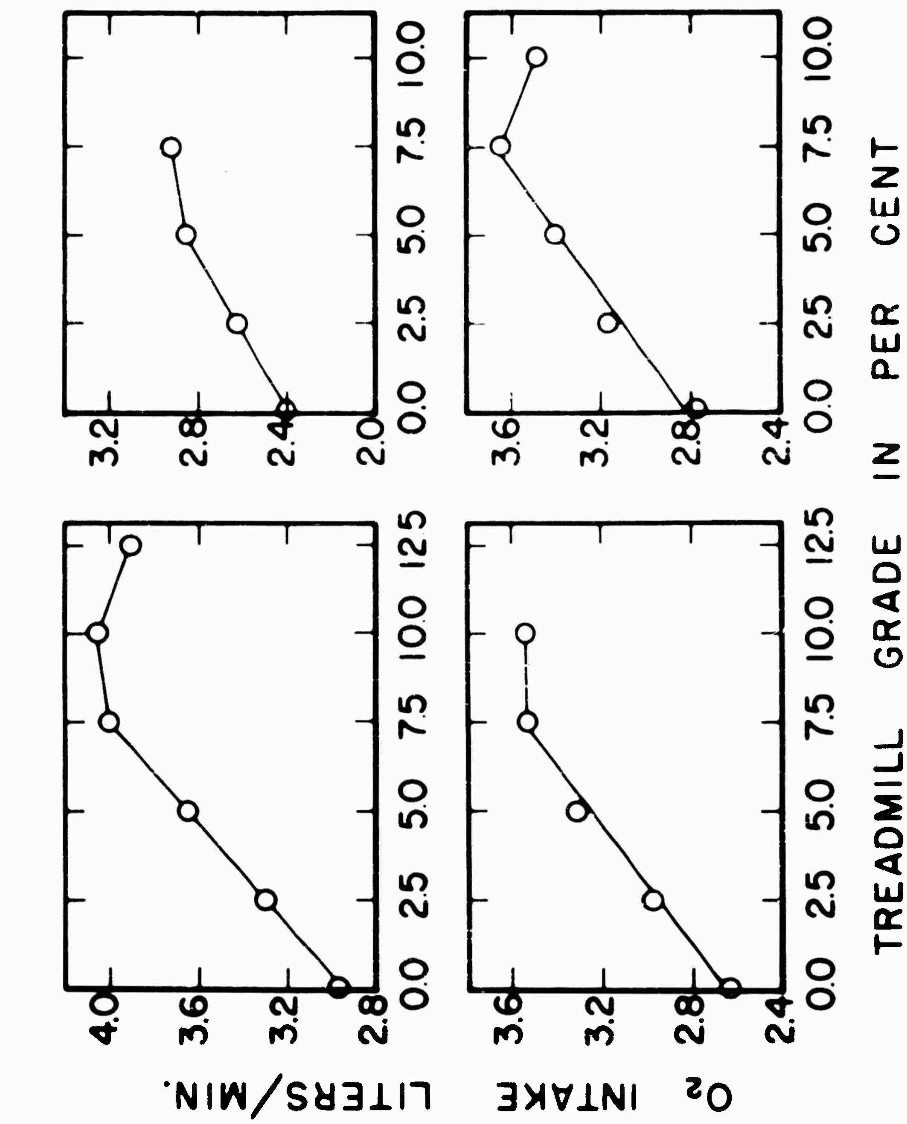

Figure 5. Change in oxygen consumption with change in treadmill grade. Treadmill speed — 7 mph.

An indication of the sensitivity to change in the opposite direction is given by physical conditioning. Table 3 shows the evaluation in maximal oxygen intake that occurred in ten men who were conditioned for cross-country running. The increase in this instance is of the order of 10 percent. However, larger increases with training have been reported by others.

With respect to reliability of measurement, the coefficient of reliability was found to be 0.95 in 60 test-retest determinations. In addition, test results have been shown to remain very stable over a period of one year in men whose physical activity was relatively constant over this period of time. Thus, one can depend on a reasonably "fixed" baseline in longitudinal stress studies covering periods of weeks or months.

In summary, our conclusion, after considerable experience with this test, is that useful information with respect to cardiovascular-respiratory function in severe work is obtainable by careful application of the maximal oxygen intake test.

TABLE 3.

CHANGE IN MAXIMAL OXYGEN INTAKE WITH DEHYDRATION, PHYSICAL CONDITIONING AND THE COMBINATION OF ACCLIMATIZATION TO HEAT AND PHYSICAL CONDITIONING

Group	Man	Δ $(D_1 - N_1)$	Δ $(D_2 - N_2)$	Δ $(N_2 - N_1)$	Δ $(D_2 - D_1)$
Conditioned (C)	Ca	0	—0.09	+0.09	0
n = 5	Che	—0.15	—0.25	+0.07	+0.08
	Mu	—0.10	—0.28	+0.02	—0.16
	Per	—0.07	—0.06	+0.53	+0.43
	Da	—0.14	—0.24	+0.39	+0.29
$\bar{x}$		—0.09	—0.18	+0.22	+0.19
Acclimatized	Wi	—0.32	—0.34	+0.70	+0.68
and	Cha	—0.21	—0.25	+0.34	+0.30
Conditioned (AC)	Gr	—0.55	—0.22	+0.06	+0.39
n = 5	Co	—0.45	—0.29	+0.27	+0.43
	Mc	—0.18	—0.16	+0.15	+0.17
$\bar{x}$		—0.34	—0.25	+0.31	+0.39
Sedentary (S)	Bu	—0.06	—0.12		
n = 3	Ke	—0.16	—0.18		
	Pea	—0.30	—0.32		
$\bar{x}$		—0.17	—0.21		
$\bar{\bar{x}}$ (n = 13)		—0.21	—0.22	+0.27 (AC&C)	+0.26 (AC&C)

N_1 and N_2: Max. $\dot{V}O_2$ when normally hydrated; measured the day before D_1 and D_2, respectively.

D_1 and D_2: Max. O_2 at 1st and 2nd dehydrations, respectively.

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Fixed Work Load. One of the most frequently used work tests involves fixed low level work, commonly called "aerobic" work, (walking, e.g. 3.5 mph, 10 percent grade). It is well known that continuous work regarded as moderate by the "normal" individual can easily become severe to the "stressed" individual. Numerous examples can be cited, but the most common perhaps is work in the heat (acclimatized vs. non-acclimatized state).

The changes over days in the heat in work pulse, rectal temperature, and sweat rate (commonly used parameters for evaluating work performance) are shown in Figure 6. In general, work pulse rate decreases, rectal temperature decreases and sweat rate increases with days in the heat. If a work pulse rate of 180 is taken as an index of "work capacity" one can see that walking 3.5 mph, (10 percent grade for 30 minutes in 90°F. Dry Bulb, 80°F. Wet Bulb) apparently is the "work capacity" level for the first two days in the heat. Thereafter, the work plus environmental stress no longer summates to a work capacity level, and the work pulse falls.

Another example of the use of a fixed low level work task may be cited. Recently, we acutely dehydrated 13 men overnight in the heat (115°F. Dry Bulb and 80°F. Wet Bulb). After they were dehydrated to a 5 percent body weight loss they were permited to rest for three to six hours until they were no longer hyperthermic (elevated rectal temperature). After the rest, they were asked to walk on the treadmill at 3.5 mph, 10 percent grade in a 78° F. Dry Bulb environment. Figures 7 and 8 show pulse rate and rectal temperatures, respectively, during the walk and recovery when the men were dehydrated (D_1 and D_2) and also when they were normally hydrated (N). Both mean pulse rate and rectal temperature were significantly elevated after dehydration. Again the mean pulse rate was elevated to values close to the value of 180 cited by Dr. Balke as a pulse rate closely identified with the limit of physical work capacity.

A note of caution should be injected, however; it is common to make the assumption that factors which produce a high work pulse are accompanied by poor cardiovascular performance. With the mild dehydration and acidosis accompanying semi-starvation no change or even a decrease in walking pulse rate occurred. (In contrast, this was accompanied by a large loss in maximal oxygen intake.) The bradycardia associated with semi-starvation completely changed the cardiovascular picture as represented solely by heart rate.

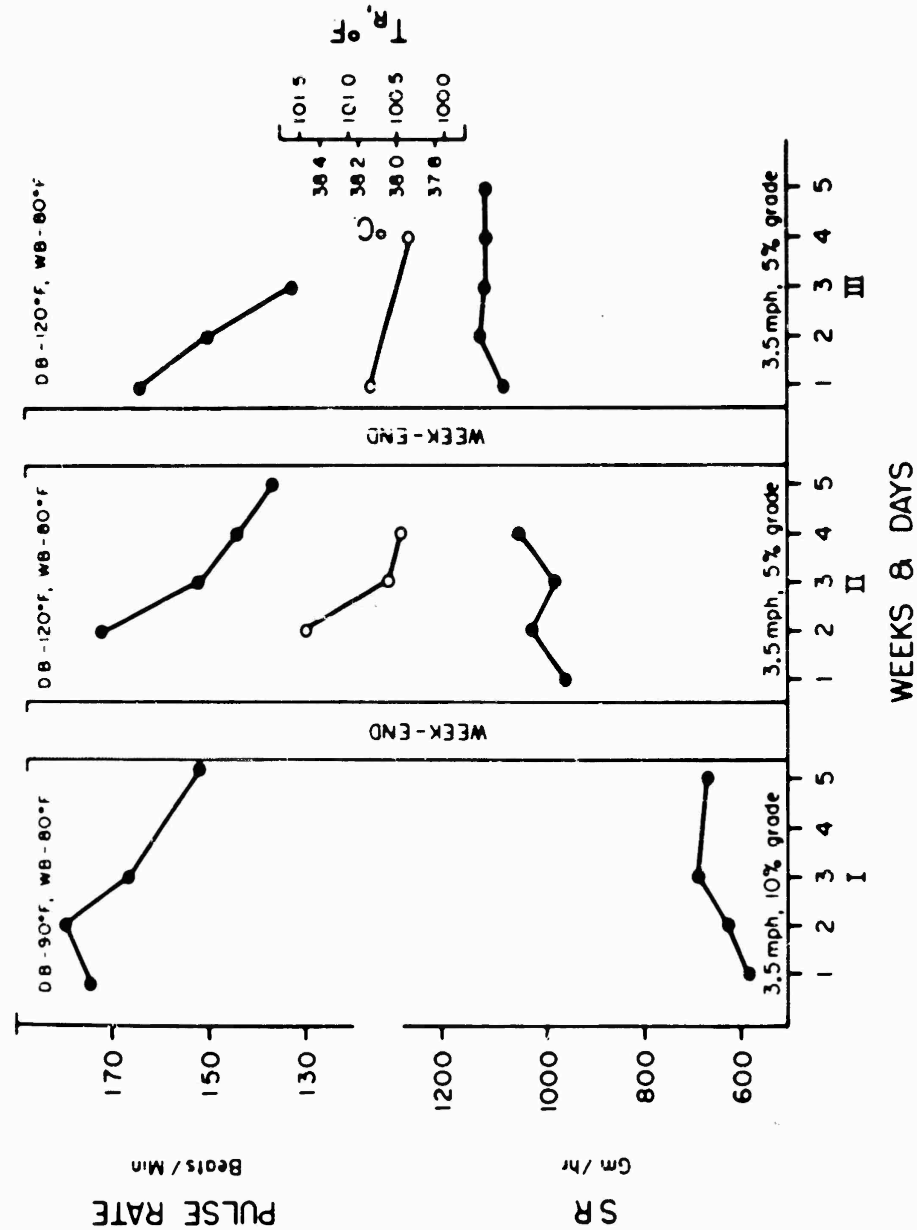

Figure 6. The effect of heat acclimatization on pulse rate, sweat rate (SR) and rectal temperature (T_r) during walking. Note that working conditions varied between weeks I and II.

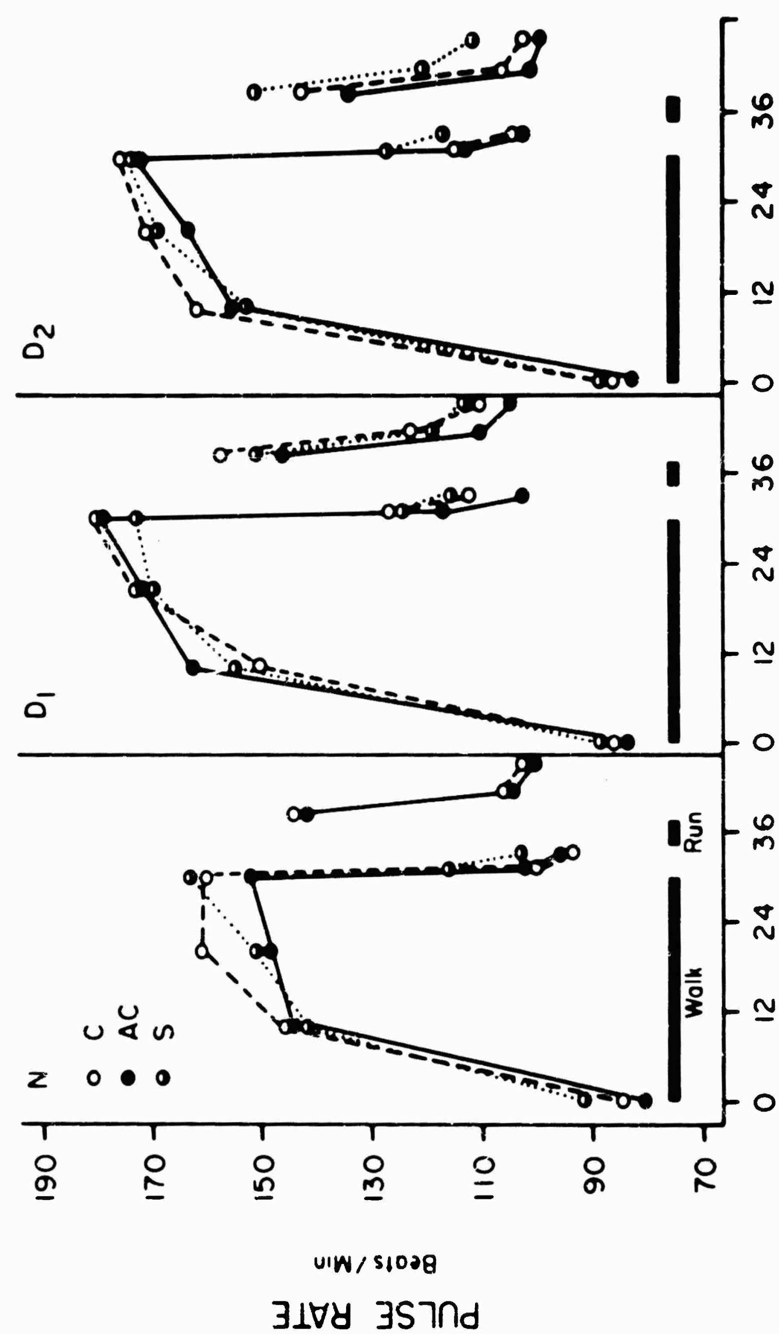

Figure 7. Pulse rate during work and recovery in men who were normally hydrated (N) and dehydrated (D_1 and D_2). Three groups of 5 men each were observed: Group C — physically conditioned, Group AC — acclimatized to heat and physically conditioned, Group S — sedentary.

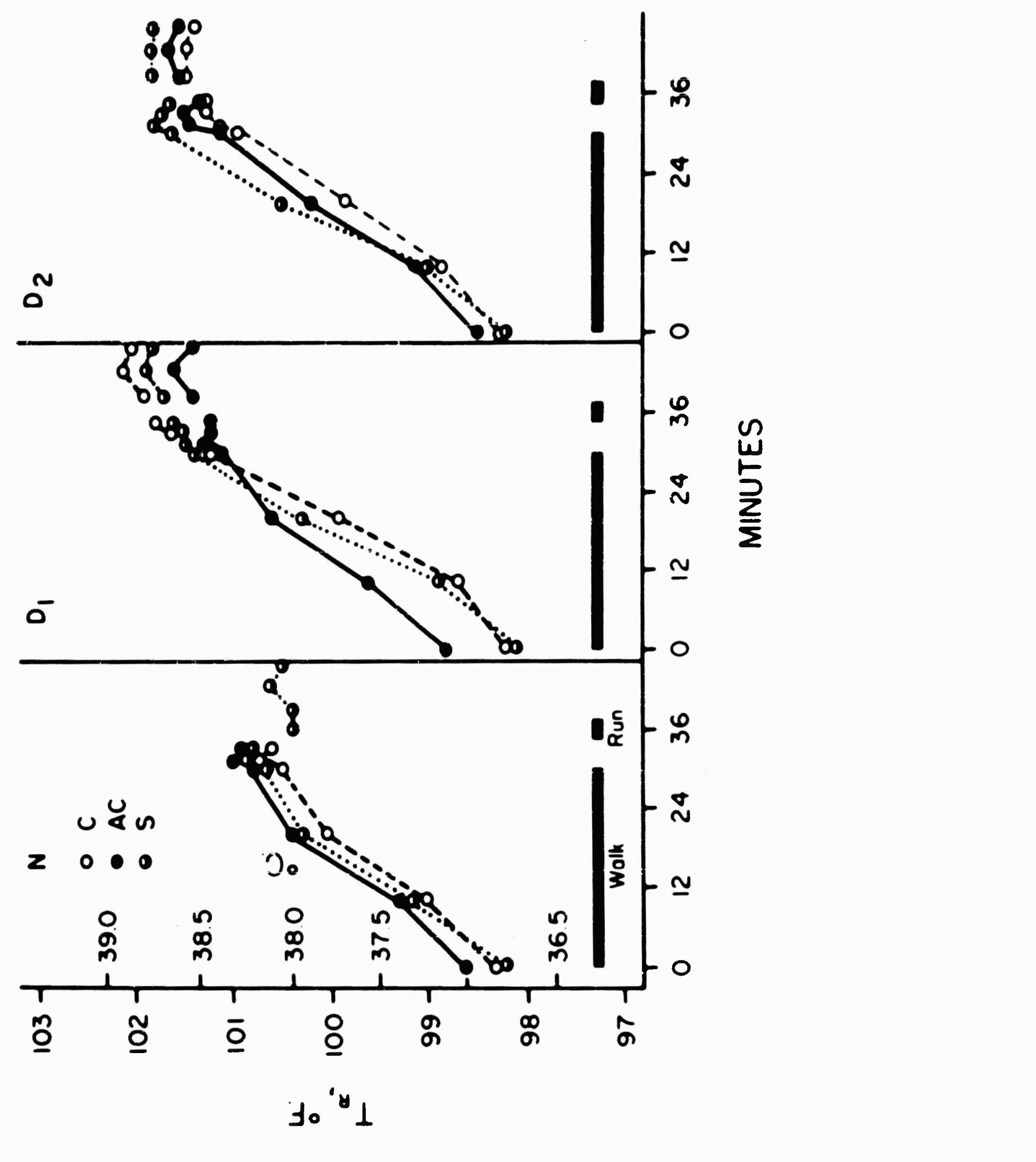

Figure 8. Rectal temperature (T_r) during work and recovery in men who were normally hydrated (N) and dehydrated (D_1 and D_2). Three groups of 5 men each were observed: Group C — physically conditioned, Group AC — acclimatized to heat and physically conditioned, Group S — sedentary.

This discussion of three different work tests should not be regarded as a complete treatment of these tests. Each of the tests has certain applicability in the assessment of physical work performance and/or capacity, but *ad lib* substitution of one test for another cannot legitimately be made. Rather than depending on one "best" test it would seem wise to depend on the synthesis of information from a test battery — which might or might not include the tests presented. We have routinely supplemented the above tests with: blood chemistry determinations before, during, and after aerobic and anaerobic work tasks, psychological and motor performance tests, including strength measurements and tests of the speed of arm and leg movement. Thus, the test battery provides a picture of "physiological status" that would be exceedingly hard to duplicate in any other way.

SIGNIFICANCE AND LIMITATIONS OF LABORATORY STUDIES ON FITNESS

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The problem of the limitations of laboratory studies is common to studies on performance capacity carried out in a variety of contexts. The work of the Laboratory of Physiological Hygiene has been concentrated in the nutritional area and this is the framework to which the comments to be made apply directly. An attempt will be made, however, to consider the topic in more general terms.

Research on performance capacity under conditions of laboratory study has merits inherent in (1) the control of environmental and motivational variables, (2) the possibilities of a systematic examination of the specific (e.g., dietary) factors, and (3) a comprehensive characterization of fitness. However, the limitations must also be borne in mind.

Methodologically, applied research can be no more sound than the tools provided by the basic disciplines. The unfinished mapping of the principal dimensions in the area of psychomotor performance results, necessarily, in hesitations in the selection of tests of motor performance. While studies on this problem have not been lacking, the search for factors important in the performance of a wide variety of psychomotor tasks is not completed. In particular, the relationship and relative value of factorially "pure" tests versus tests sampling a number of abilities at one time requires further study.

There is little doubt that for purposes of *selection* of candidates for a specified job the "job analogy" tests are preferable. If *classification* rather than selection is one's principal concern, the need is intensified for measuring maximally independent motor abilities which may be weighted differentially in predicting performance in a wide variety of jobs. In investigations of performance deterioration under "stress," the problem is still more complex. These are, as a rule, interdisciplinary studies in which behavior is only one of the several facets of human biology that are examined. The matters of economy of time and effort, both on the part of the investigator and the subjects and of the testing space become of paramount importance. Furthermore, under stress (including nutritional stresses, especially if they are severe and the "nutritional status" is changing fairly rapidly) the problem of characterizing complexly defined fitness at a "given time" poses severe problems in the scheduling of the testing operations.

Agencies of the Armed Forces providing research support on stress and fitness are anxious to obtain information regarding anticipated performance capacity under various feeding situations in the field. In evaluating laboratory studies it is desirable to translate the observed responses of the human organism into terms meaningful for military planning purposes. Ideally, from the military standpoint, the various morphological, biochemical, physiological measurements should be integrated into a single index of "performance capacity" so that deviations from "good normal" performance capacity could be expressed in simple terms, such as "percentage of normal." It is further considered desirable to determine at what percentage of this good

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normal performance the success of military operations would be seriously endangered.

It should be recognized that at the present stage of our knowledge these requirements can not be met rigorously. In a larger sense, the desiderata oversimplify the problem beyond realistic limits. The multiplicity of operations involved in modern warfare is the first stumbling block. A meaningful integration of biochemical and physiological measurements can be undertaken only if a particular type of performance is chosen, such as walking or running. Even then there is no information that would enable one to translate a rise in work-pulse from 129 beats per minute to 151 beats per minute after one hour's walk on a treadmiii, observed after four days of acute starvation with hard work, into a decrement in the soldier's ability to march in a specified terrain (4). If in physiological investigations on stress this simply cannot be done because of the lack of the required validation, how much more difficult is the practical interpretation of a statistically significant deterioration in the test of eye-hand coordination and the increment in body sway (1).

It may not be out of place to point out that in the acute starvation experiment just referred to there was no significant decrement in grip strength while large losses in strength were noted in *prolonged* caloric restriction. A marked deterioration in coordination, but no significant changes in strength (2) were noted in young men maintained on diets practically free of vitamins of the B complex. Thus, dietary deficiencies result in different *patterns* of functional deterioration, and the changes in fitness cannot be graded along a *single continuum*. Deficiency of vitamin A, resulting in the deterioration in the capacity for dark adaptation in the absence of biochemical signs of deficiency other than low levels of vitamin A in the plasma, may be noted as the extreme case of specificity of the effects of nutritional stresses. While this symptom would be of very high practical importance, resulting in a significantly impaired capacity for any night operations, its presence could not be detected by methods valid for evaluating capacity for physical work (locomotion), nor could the scores be simply "subtracted" from a hypothetical general fitness score. "Fitness" is and must remain a multi-dimensional concept.

What can be done legitimately with the data that are available is to compare different nutritional and environmental conditions in terms of their impact on different facets of fitness (3). Thus strength, measured by grip dynamometers, showed a very marked decrement in prolonged semi-starvation while acute starvation for five days, maintenance on 580 calories per day for 12 days, and subsistence on the daily intake of 1010 calories for 24 days were not associated with a statistically significant or biologically important deterioration in strength.

There is another set of limitations, affecting the generalization and practical interpretation of the results, inherent in the conditions of the experiments. The "conditions" include, logically, also the subjects. For our work on survival rations the subjects were selected among Army volunteers on the basis of rigorous health examination, evaluation of the officers in charge, and personal interviews with the applicant. The character of the studies, demanding a full cooperation on the part of the subjects, was made clear at the outset. Additional screening was made in the course of physical conditioning during several weeks prior to the arrival of the subjects in Minneapolis. On one occasion a man was returned to Fort Lee

when it became apparent that his motivation was not up to the standard. Thus, in laboratory studies on nutrition and performance we work, as a rule, with subjects selected for their stamina and high motivation. The instructions and the test situations are structured so as to maintain a high level of effort throughout the experiment. This is important, if actual performance is to be regarded as an index of capacity, i.e., of the physiological status of the organism, but the level of top motivation is not always achieved and maintained. However, the emphasis is legitimately on "Let's see what you *can* do even when the going gets tough." Under these conditions the observed deteroriation in *performance* will be minimal and not characteristic of changes to be expected in subjects of lesser initial stamina or whose morale is less resistant to discomfort. This point must be taken into account in extrapolating the information obtained in the laboratory in terms of performance in the field. It is clear that field testing is a necessary supplement and extension of rigorously controlled laboratory investigations.

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A FIELD TEST OF HEAT TOLERANCE*

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For the past five years Dr. R. E. Johnson and I, together with a large group of military and civilian collaborators, have been studying the problem of the all-purpose survival ration for the U. S. Air Force. Our total experience encompasses 8700 man-days of observations on 212 healthy young males kept under strictly controlled metabolic conditions (1, 2, 3, 4).

The guiding philosophy in our investigations has been that the man as a whole is the measure of performance capacity. An "index," no matter how tantalizing and intriguing it seems to be, may be misleading. It is an empirical and restricted abstraction. The holistic approach of the clinician will, in the long run, prove to be the more fruitful. Our experience with normal young men living under conditions of simulated survival amply supports this conviction.

In the field tests which we have conducted, we developed combined procedures to measure simultaneously the functional status of several important organs and systems. One such procedure designed to evaluate heat tolerance was called the *heat acclimatization test* so that the subjects would not become unduly alarmed about the prospects of participating in a test of endurance or tolerance. Since a detailed description of this test will be published in a forthcoming Air Force Technical Report (3), we shall here only summarize the protocol and later** we shall discuss some of the observations and their significance.

Figure 1 is a schematic presentation of the heat acclimatization test. This test was successfully conducted 20 times on 100 healthy young men. The subjects were tested in groups of 25. They reported outside a standard barracks in the afternoon. Their forearms had been previously shaved. They rinsed their forearms with distilled water. Next they went into a latrine in the barracks and urinated, the time being accurately noted. They stripped and were weighed on a platform scale sensitive of one ounce (30 gm). They dressed in shorts, socks, and brogans and lay down in groups of five on a pentagon of beds. While on the beds we measured rectal temperature and pulse rate. Both forearms of each subject were enclosed in obstetrical length rubber gloves and the skin temperature within the right glove and on the bare right upper arm was measured. When these procedures were completed, the men went out onto a track and a second group of five reclined on the pentagon beds. The several measurements consumed about four to six minutes.

After the resting measurements had been made, the men began to march around an oval track which was approximately 0.25 miles in length. They marched at 3.75 mph. Each lap was timed by an observer so that the pace was constant. The men marched for one hour or until they could go no farther. The energy expenditure was about 290 Cal/hr, and had been so adjusted that a starving subject could probably accomplish the task. During the march observations were made every 30 minutes of dry bulb tempera-

*The work described here was supported by USAF Contract AF 18 (600)-80.

**These observations are included in section on "Effect of Environmental Stresses on Performance Capacity."

ture, wet bulb temperature, wind velocity, and state of the sky. By the end of 30 minutes all 25 men were marching as a platoon and each group of five was separated in time by eight minutes (or two laps). Throughout the march a medical officer was in constant attendance.

After the distance had been covered, the men reported immediately to the pentagon of beds in the original groups of five. There we measured the pulse rate, skin temperature on upper arm and under glove, and, after removing the gloves, the rectal temperature. The subjects then stripped and were weighed. They urinated again at a known time so that we had a timed urinary specimen representing the period of marching. In another barracks they rested one hour, after which we collected a second timed specimen of urine. The sweat from the two gloves was pooled, its volume was measured, and aliquots were preserved for qualitative and quantitative chemical study.

By means of this test and concurrent clinical study of the volunteer subjects we were able to arrive at several significant generalizations regarding the effects of water deprivation and diet on capacity of the potential castaway to perform in moist heat.

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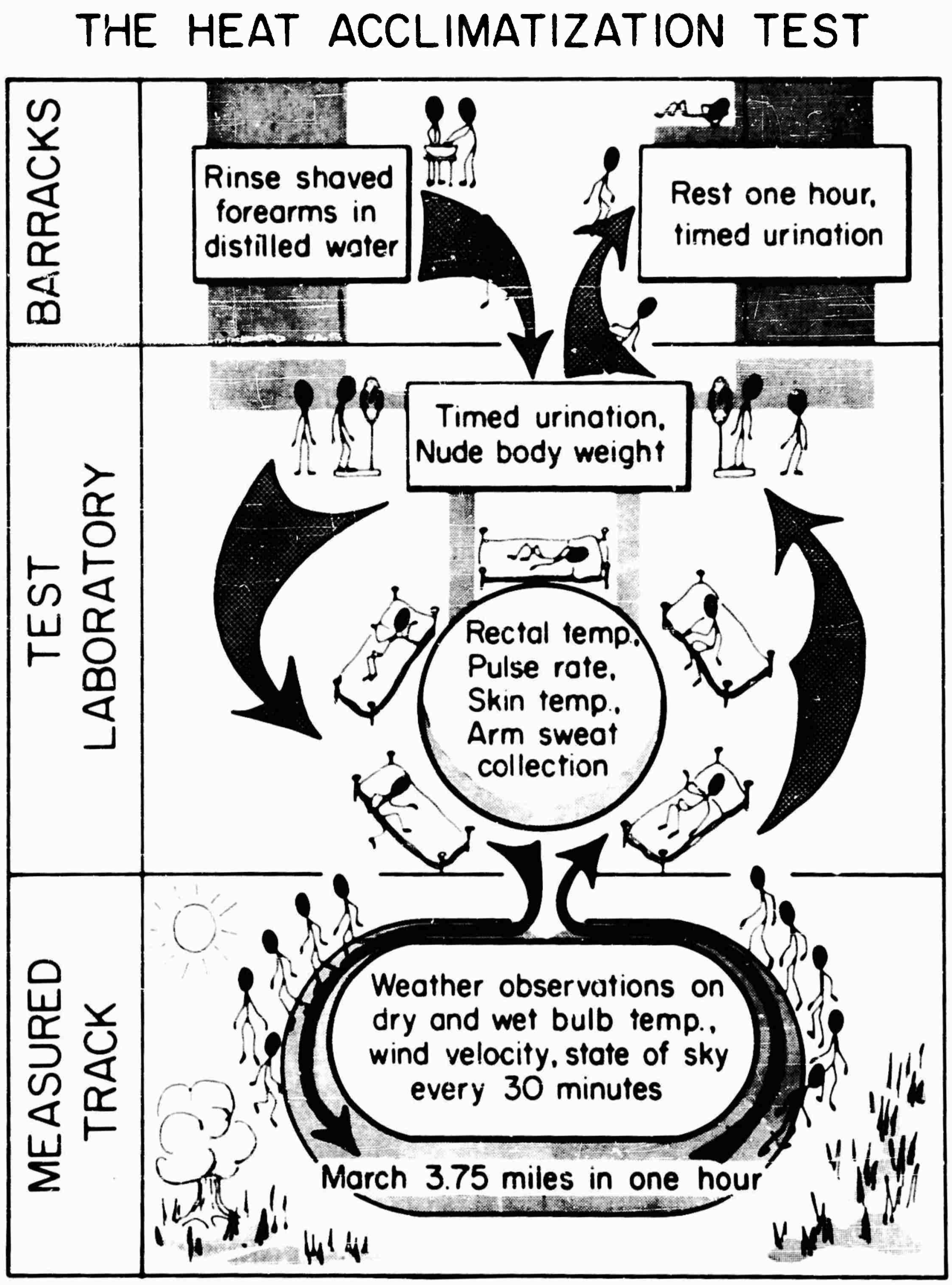

Figure 1. A Field Test of Heat Tolerance.

DIFFERENTIAL DIAGNOSIS IN FIELD STUDIES*

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L. J. Henderson had a great deal of influence on the thinking of many, if not most, of us here in this room, and I should like to remind you of some of his ideas. His scientific contributions had a common theme, the quantitative associations among many interrelated variables, whether they be in acid-base balance (1) or in the ecological relationship between organism and environment (2). For private consumption by us in the Fatigue Laboratory he might say, "There is no such thing as fatigue; only fatigues," or "There is no such thing as fitness; only fitnesses." Many times I have heard him say, "Often the obvious is the most important." With this preamble, I shall describe the methods we have applied in studying the very important nutritional problem of survival rations.

As it has evolved in clinical medicine, the most characteristic application of the scientific method is the differential diagnosis. The physician is faced with the intellectual problem of deciding precisely what is wrong with a human being. The inductive process involves finding out everything pertinent about the patient; the deductive process involves deciding what disease process will explain the findings. Long experience has proved that effective diagnosis must include certain kinds of information, no category of which can be neglected without imperiling ultimate accuracy.

A. History

1. Present chief complaint.
2. Family history, for ecological and heredity factors.
3. Patient's past illnesses, which may leave indelible marks on his present status.
4. Course of present disease.

B. Physical Examination

1. Inspection, palpation, percussion, auscultation on an orderly basis by systems.
2. Examination by instrumental extensions of the physician's senses, e.g., the ophthalmoscope.
3. Psychiatric examination.

C. Laboratory Examination

1. Techniques of morphology, e.g., hematology.
2. Biophysical techniques, e.g., the electrocardiogram; the X-ray.
3. Biochemical techniques, e.g., measurement of concentration of important constituents in blood, urine, or other body fluids. These tests customarily may be qualitative or preferably quantitative.

*The work described here was supported by USAF Contract AF 18 (600)-80.

4. **Physiological techniques, e.g., measurement of metabolic rate; assessment of renal function.**

5. **Psychological and psychiatric techniques, e.g., various tests of emotional and intellectual capacity.**

The diagnostician must think of deviations from normal at various levels of organization: sub-cellular, cellular, tissue, organ, system, organism as a whole, social group. He must think simultaneously of various kinds of possible pathological processes whether from intrinsic or extrinsic causes: congenital, inflammatory, degenerative, neoplastic, toxic, metabolic, nutritional, traumatic, or from physical agents such as heat, cold, and radiation. He knows that most of his observations will be "negative" in the sense that they show no deviations from normal limits. He knows that sometimes, but only rarely, a diagnosis can be made with some certainty from history alone (e.g., angina pectoris), examination alone (e.g., gout) or laboratory tests alone (e.g., pulmonary tuberculosis). He interprets his laboratory findings with caution, and in relation to all the other facts he knows about the patient. He is always aware that changes in one system may provoke changes in others. Anyone who has suffered a severe bout of diarrhea, for instance, knows what a considerable effect a deranged gastrointestinal tract may have on general physical and mental capacities.

Details of the actual methods we employed will be found in three technical reports to the Air Force (3, 4, 5). Here, I wish to present certain generalities. Our application of differential diagnosis was aimed at following possible deterioration in previously healthy subjects. Hence, we followed the daily symptoms in detail, administered careful physical examinations at stated intervals, and carried out periodically a variety of morphologic, biophysical, biochemical, physiological, and psychiatric studies. We had to determine the combined effects of the independent variables: environmental temperature; calorie intake; water intake; intake of various percentages of protein, carbohydrate, and fat; and daily work load. Ultimately we had to try to arrive at an answer to the question, is deterioration less marked for one nutrient regimen as contrasted with others? The statistical approach to answering this question had to be different from classical methods of differential diagnosis. We ended up with a mass of quantitative data on organ function, and a series of positive, but non-quantitative, clinical findings on the subjects. Both kinds of information had to receive due weight in the final decisions, so to speak, on the final "diagnosis" of each nutrient combination.

The experimental nutrient mixtures are described in Figure 1. The codes should be noticed, as they appear in future figures. They are based on total calories, percentage of calories from protein, carbohydrate, and fat, and water intake. It would be expected, as indeed we found, that different manifestations would be caused by different nutrient mixtures. In other words, there would not be a single kind of deterioration, but many different kinds. For example, dehydration would ensue with limitation of water, weakness with starvation.

It was to be expected that some of our observations would be positive in the sense of discrimination between regimens. Figure 2 shows these positive measurements for the winter study. They were mostly related to organ function or nutrient balance and a good argument can ge made for each as being a valid consideration in differential diagnosis. It was also to be expected that many observations would be non-contributory, in the sense that

they did not change in two weeks of undernutrition. Figure 3 lists some of these non-contributory observations in the winter study.

Statistically, the way we handled these quantitative data was to take those 17 which were contributory, and to assign to each of the 21 regimens a number from 1 (best) to 21 (worst). These numbers were then segregated into four quartiles of rank order for each regimen, with results for the hard work groups, winter study, as shown in Figure 4. Particular attention should be paid to the first quartile (best attributes) and fourth quartile (worst attributes). When a particular regimen ends up with a lot of bad scores, down around 17 or 18, there are some things seriously wrong with it. Starvation has very few points in the first quartile, many in the fourth; 3000 calories of a normal diet is the reverse. Addition of calories improves the position of any given regimen. Enforced water deprivation decreases the position of any given regimen.

This statistical approach has been applied in temperate, winter, and summer studies. It permits the quantitative functional data to be given due consideration, along with the clinical findings, in the final assessment and comparison of one possible survival ration with another. Our general conclusions will be summarized later in the proceedings.

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EXPERIMENTAL NUTRIENT MIXTURES

(WINTER 1954)

EXPERIMENTAL RATIONS AND OTHER FOODS USED	CALORIC INTAKE	% DISTRIBUTION OF CALORIES	SYMBOLS USED IN TABLES AND FIGURES
Pre Period: 5-in-1	c 3200	14%P/53%CHO/33%F	PRE, Day 0
Recovery: 5-in-1 in REC I and A Ration in REC II	——	——	REC
Negative Control Starvation	0		ST. 0
Spice Drops, Starch Jelly Bar, Hard Candy	1000 and 2000	0%P/100%CHO/0%F	0/100/0 1000 0/100/0 2000
Saltines, Oleomargarine	1000 and 2000	3%P/18%CHO/79%F	2/20/78 1000 2/20/78 2000
Meat Bar	1000 and 2000	30%P/0%CHO/70%F	30/0/70 1000 30/0/70 2000
Meat Bar, 5-in-1 Crackers, Raisins, Catsup, Jam*	1000 2000 and 3000	12%P/58%CHO/30%F 14%P/53%CHO/33%F	15/52/33 1000 15/52/33 2000 N - 3000
Ration Control: A Ration	——	——	CONTROL
Water Limited: 910 ml/day			L
Water Unlimited: ad libitum			U

* Positive Control at 3000 Cal./Day

Figure 1. Differential Diagnosis in Field Studies.

RANK-ORDER OF NUTRIENT COMBINATION
Hard Work   Winter 1954

MEASUREMENT Second Week of Experimental Period or Lowest Value during Experimental or Recovery Period.	NUTRIENT COMBINATION [illegible] 3000		30/0/70 2000		15/52/33 2000		2/20/78 2000		0/100/0 2000		30/0/70 1000		15/52/33 1000		2/20/78 1000		0/100/0 1000		ST. 0	
	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L
Body Composition																				
1. Body weight, least loss	1	4	6	10	2	18	8	15	7	11	3	16	5	13	13	8	13	17	19	20
2. Body water, least loss	4	15	1	20	3	12	2	9	5	18	6	12	7	7	8	16	10	14	11	19
3. Water diuresis test	3	16	4	18	8	19	2	15	10	8	11	20	9	17	1	14	6	12	13	4
Kidney Function																				
1. Osmotic parameters																				
a. Mean 24-hr urinary volume	13	10	18	12	15	8	20	5	7	2	7	9	19	6	16	4	14	1	11	3
b. U/S ratio	5	20	14	18	3	15	2	10	4	1	1	12	13	16	8	17	6	7	9	19
2. Creatinine clearance (EI)	12	2	1	7	4	5	10	8	19	18	16	10	9	6	3	20	16	18	14	13
3. Serum non-protein nitrogen	9	9	14	20	8	16	2	14	2	6	10	8	6	16	4	12	2	8	10	16
4. Addis count																				
a. Red blood cells	13	5	5	5	5	5	18	5	12	17	5	11	5	5	5	14	16	20	15	19
b. Casts	7	18	7	7	7	16	7	7	7	17	7	7	7	7	7	7	14	20	15	19
Endocrines																				
1. Blood sugar (EI)	2	6	20	17	11	13	6	7	16	2	19	18	9	14	14	2	11	4	8	1
2. 17-ketosteroids	3	4	6	6	2	8	11	15	17	2	18	18	14	9	11	14	11	7	20	16
3. Serum chloride, least change	10	10	7	4	10	14	1	4	10	16	20	4	14	4	17	4	18	10	19	10
Liver Function																				
1. Serum cholinesterase	5	3	9	4	1	6	6	2	16	12	10	16	18	13	16	8	19	12	20	16
Gastrointestinal Function																				
1. Serum amylase	1	10	13	10	11	2	8	18	2	6	16	5	6	14	19	12	4	7	20	15
Balances																				
1. Calorie	1	2	14	4	5	6	10	7	9	3	8	14	11	16	17	12	18	15	19	20
2. Water	1	11	5	20	4	15	12	13	7	3	2	19	7	15	17	9	10	7	15	18
3. Nitrogen	2	6	1	7	5	4	12	8	10	9	3	12	12	16	19	18	14	14	17	20
4. Chloride	16	17	19	20	18	14	3	1	8	6	10	16	5	2	9	13	4	7	12	11
5. Sodium	2	3	8	5	4	2	14	6	13	12	7	11	9	10	18	19	16	16	20	17
6. Potassium	5	12	1	2	6	4	18	13	17	6	3	10	20	12	15	15	20	8	15	8
7. Ketonuria (> + 2, E II)	10	5	8	18	5	5	12	12	5	5	8	18	5	5	18	14	5	5	12	15
Total Score	125	19[illegible]	191	234	137	207	184	194	203	200	210	276	210	233	255	252	247	229	314	309
General Rank	1	5	4	14	2	9	3	5	8	7	10	18	10	13	17	16	15	12	20	19

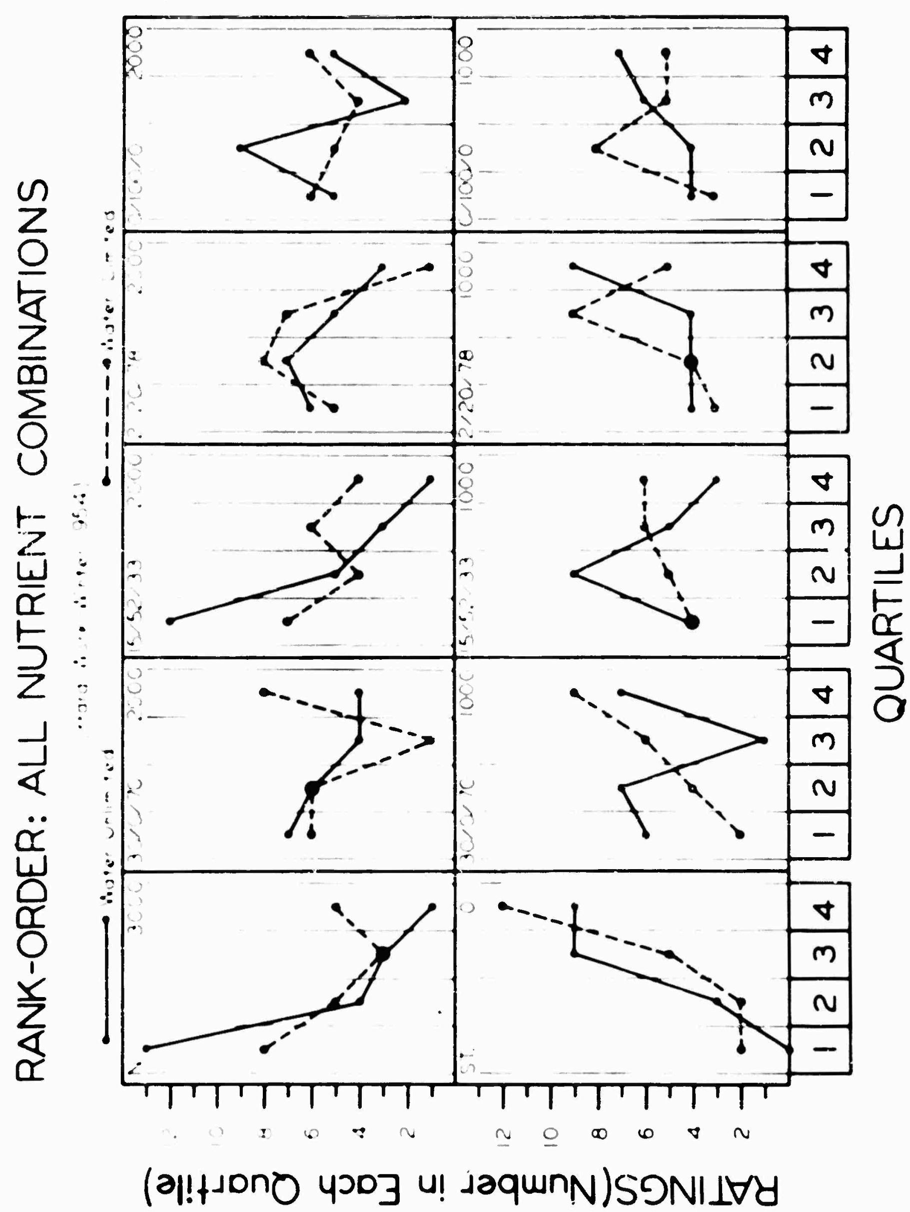
Figure 2

MEASUREMENTS STUDIED, NOT USED FOR RANK-ORDER. RELATION TO SURVIVAL POTENTIAL UNPROVEN.

Quantities Unchanging During Experimental Period.	Quantities Teleologically Unrelated or Autocorrelated Regardless of Experimental Result.
Endocrines 1. Serum sodium 2. Serum potassium 3. Serum calcium 4. Serum inorganic phosphate 5. Serum alkaline phosphatase 6. Minute urinary creatine Liver Function 1. Serum total cholesterol Cardiovascular Function 1. Resting blood pressure 2. Electrocardiogram Hematology 1. Hematocrit	Body Composition 1. Body fat Renal Function 1. Minute urinary volume 2. Albuminuria 3. White blood cells 4. Epithelial cells 5. Serum osmolarity 6. Urinary osmotic excretion 7. Osmolar clearance 8. Serum creatinine 9. Minute urinary creatinine Gastrointestinal Function 1. Fecal wet weight 2. Fecal fat 3. Occult blood 4. Fecal muscle fibers Respiration Function 1. Oxygen consumption* 2. Carbon dioxide production* 3. Pulmonary ventilation* Cardiovascular Function 1. Resting pulse rate Central Nurve System 1. Passage of time 2. Electroencephalogram Hematology 1. Erythrocyte sedimentation rate* 2. Total white cell count 3. Differential white cell count Balances 1. Calcium 2. Urinary phosphorus* 3. Urinary pH and titrable acidity 4. Urinary ammonia nitrogen 5. Intake of fat and carbohydrate Physical Fitness

*Data incomplete or considered to be technically unreliable.

Figure 3



RANK-ORDER: ALL NUTRIENT COMBINATIONS
RATINGS(Number in Each Quartile)
QUARTILES

Figure 4

HEART RATE AS AN INDEX OF PERFORMANCE UNDER FIELD CONDITIONS

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As an applied physiologist working in close contact with the Armed Forces in the Arctic, I have learned that the capacity for performance of the soldier is greatly affected by the type of clothing, equipment, or diet that he is given. For this reason, the ideal way of testing the performance of an item which will be used by troops is to assess the performance capacity of human subjects while performing with the item concerned.

The evaluation of performance capacity under field conditions presents a number of problems. The conventional method of oxygen consumption measurement is not only impractical, if not impossible, under certain conditions, but may at times be misleading if used as the only criterion for performance impairment (5). Since the heart rate is, on many occasions, more informative than other methods of assessing performance, and easy to use even under field conditions, we have decided to elaborate the procedures of Mueller (7) in order to be able to use this method with sufficient reliability under field conditions. Before reporting a typical experiment on the evaluation of performance under field conditions, I would like to report a few preliminary studies which were carried out prior to this field test. Figures 1 and 2 are self explanatory and clearly illustrate the fact that the work and the recovery pulse rates are informative not only of the intensity but also of the duration of work performed. Furthermore, as shown in figure 1, if the speed of walking is varied from 3.1 to 4.5 mph, the heart rates rapidly level up and quickly drop to pre-exercise levels when the activity is stopped. However, above 4.5 mph the heart rate keeps on increasing as the exercise is maintained and the recovery is progressively slower as the level and duration of the exercise are increased. The inability of the heart rate to remain at a steady state, as shown iin figures 1 and 2, would seem to indicate that stress is experienced by the heart with which the organism can not adequately cope. Indirect evidence to this effect is available from the early work of Dill (3) and from more recent studies (4, 6, 7).

I would like now to talk about a typical field study in order to show how performance may be evaluated by the use of heart rate. A few winters ago, while working in the Arctic, I was asked to participate in a study where two items of equipment were to be tested. These items were the one-man sled, which is designed to carry 75 pounds and to be operated by one man, and the two-man sled which will carry twice as much if handled by two men. We agreed not to interfere with the test and to take heart rates only during rest periods. Two groups of trained soldiers, wearing about 25 pounds of arctic clothing and carrying loads of 35 pounds on their back, were instructed to walk for 18 miles while pulling, for group A, 140 pounds with one two-man sled, and for group B, the same weight with two one-man sleds. The route to be followed was cross-country on a relatively hard, snow-covered terrain. The heart rates were taken over a period of 15 seconds at the beginning of each halt. The environmental conditions are summarized

in table 1. The test started at 8:30 A.M. If we look at figures 3 and 4, we see that group A maintained its speed constant but gradually increased the length of the rest periods with the result that the heart rate falls slowly from 121 to 113 at the end of 18 miles. The subjects of this group were not objectively or subjectively fatigued by this test. However, in group B although the length of the rest periods gradually increases, the actual speed of walking is always higher than in group A, at least until mile 16. It may be for this reason that the heart rate is progressively increasing in group B. The speed is sufficiently reduced at mile 16 and the effective environmental temperature (2) has changed sufficiently for the body to resume a neutral thermal state. It is at this time that the heart rate falls rapidly from 133 to 113. In other words, the heat lost in group B was not sufficiently large to allow a neutral thermal state. When the pulse rate is 120/min., the heat produced is approximately 350 cal./hr. (1). This level of heat production is the maximum compatible with a thermal steady state since increase in heat production above 350 cal./hr. will increase deep body temperature and sweating (8). Group B would seem to have been in this range. Consequently, test has shown that one group worked more than the other group. The difference in speed between the two groups explains this difference, since subsequent tests where the speed was controlled have failed to show any differences between the one- and two-man sleds.

This experiment illustrates the possiblity of assessing performance under field conditions. The method used is simple and sufficiently reliable. To further illustrate this point, table 2 shows that with two small groups of subjects sufficiently large differences in heart rate can be obtained which will allow detection of speed of movement even smaller than one-half mph.

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TABLE 1.

Variations in atmospheric conditions on day of the trial*.

Time of day	08:30	10:30	12:30	14:30	16:30
Solar radiation gm cal/cm /min	0.05	0.4	0.55	0.45	0.1
Wind, mph	11	10	12	10	8
Temp., °F	—8	—5	—5	—5	—4

* The two tables and four figures of this article are reproduced from *J. Appl. Physiol.*, *10*, 275 (1957).

TABLE 2.

Variations in heart rate of soldiers walking with snowshoes at different speeds.

Speed, mph	0	2.3	2.85	3.4
Group A (8)*	80 ±9**	100 ± 14	112 ± 16	128 ± 15
Group B (5)	78 ± 9	102 ± 7	114 ± 7	125 ± 7

* Number of subjects
** Standard deviation

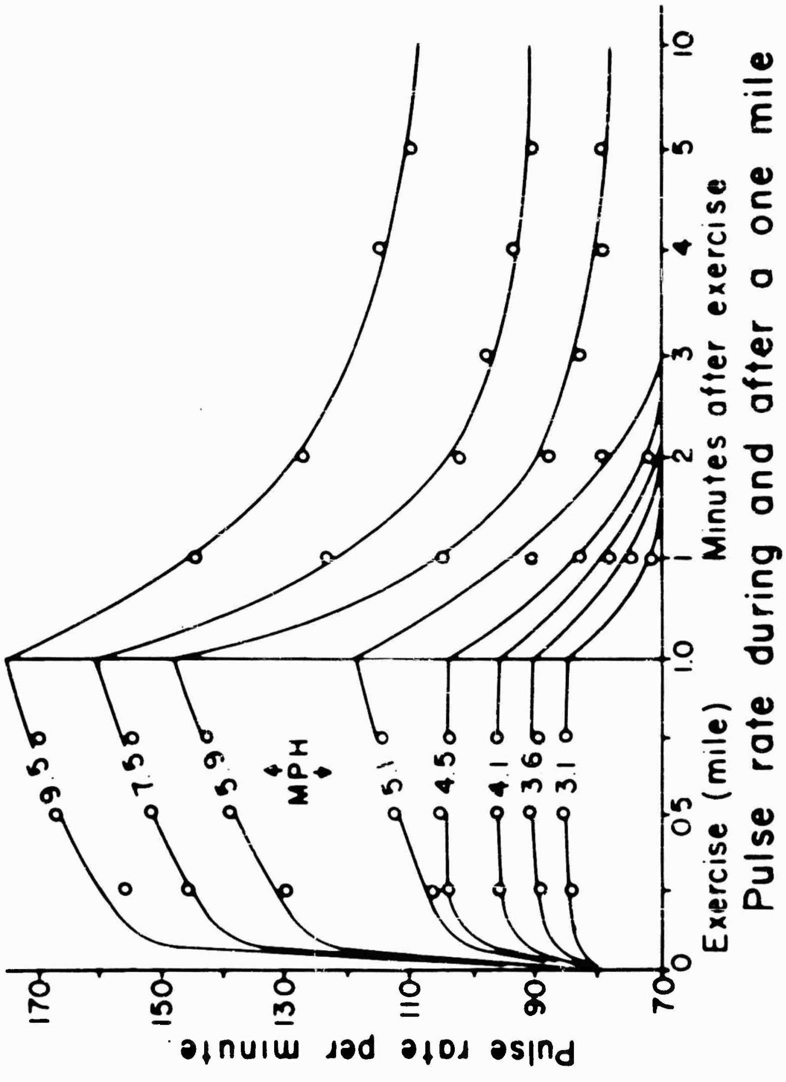

Pulse rate per minute
170
150
130
110
90
70
Exercise (mile)
0
0.5
1.0
Minutes after exercise
1
2
3
4
5
10
MPH
9.5
7.5
5.9
5.1
4.5
4.1
3.6
3.1
Pulse rate during and after a one mile walk at different speeds.

Figure 1

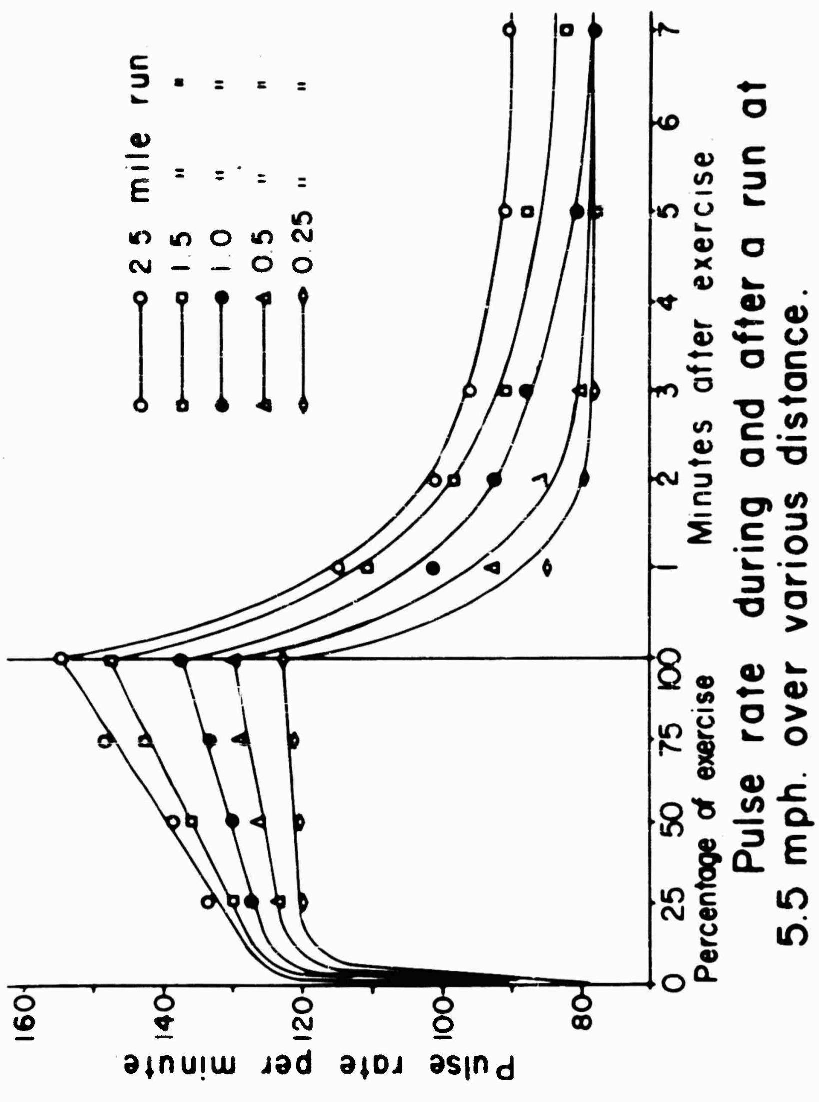

Pulse rate per minute
160
140
120
100
80
0
25
50
75
100
Percentage of exercise
1
2
3
4
5
6
7
Minutes after exercise
2.5 mile run
1.5 " "
1.0 " "
0.5 " "
0.25 " "
Pulse rate during and after a run at 5.5 mph. over various distance.

Figure 2

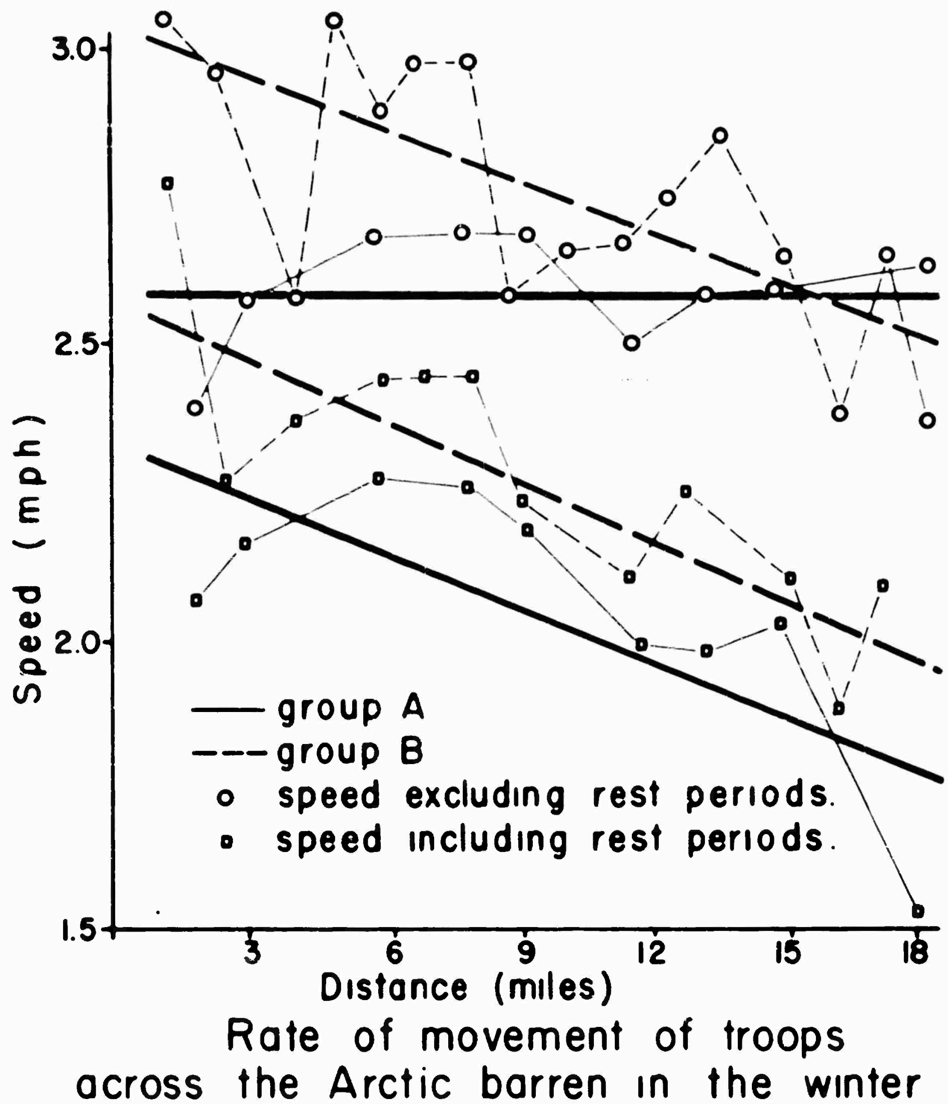
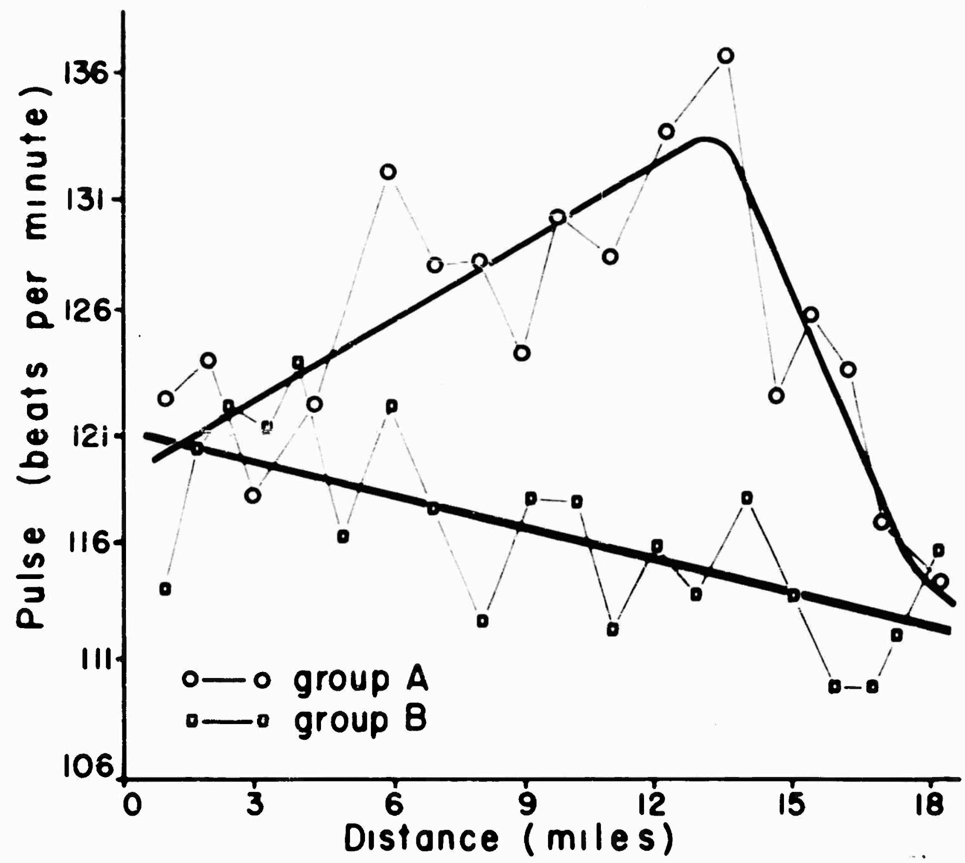

3.0
2.5
2.0
1.5
Speed (mph)
3
6
9
12
15
18
Distance (miles)
group A
group B
speed excluding rest periods.
speed including rest periods.
Rate of movement of troops
across the Arctic barren in the winter

Figure 3



Pulse rate variations of 2 groups of men walking across the Arctic barren in the winter time.

Figure 4

RESPONSES OF THE ADRENAL GLAND IN ATHLETES*

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Athletes participating in two types of sports were studied. The sympathico-adrenal system was evaluated through the excretion of epinephrine (E) and noreprinephrine (NE) in a group of amateur boxers competing in the national AAU championships. The second study was concerned with a more thorough investigation of professional hockey players. In this latter study both the pituitary-adrenal and sympathico-adrenal functions were evaluated.

Method

Catechol amines were extracted by the alumina adsorption method of von Euler and Hellner (10). The bioassay was performed by a modification of the method described by Gaddum and Lembeck (4). This method consisted of testing the sample on the rat colon for NE, and on the rat uterus for E. This bioassay is based on the quantitative inhibition by the amines of the contraction induced *in vitro* in a 2 cc. bath with acetylcholine (3, 5). The actions of E and NE on the colon are approximately equal, whereas on the uterus E is 75 to 300 times more potent than NE. When the total NE and E values were desired, the colon assay was considered sufficient.

17-OHCS was determined after beta-glucuronidase hydrolysis by the method described by Silver and Porter (8). 17-KS were determined by the method described by Pincus (7).

Amateur Boxers. Six amateur boxers competing in the finals of the Amateur Athletic Union boxing championships were studied (2). Added significance was placed on these finals because the fighters who ultimately were to win would also qualify for the finai Olympic tryouts. Enthusiasm and high state of expectancy characterized the attitudes of the fighters. This was reflected in the elevated E excretion rates observed in most of the pre-fight samples. Table 1 shows the data obtained on all fighters and the outcome of the fight.

On three fighters only one sample was obtained; on Ch and Wh the sample was a pre-contest collection. Both boxers showed elevated E excretion. Each showed ample evidence of tenseness and apprehension in the pre-fight interview. After the interview, Ch went to the corner of the dressing room and shadow-boxed for about five minutes, while Wh sat quietly on a bench, talking to his trainer, and refrained from shadow-boxing before

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entering the ring. It may be observed that Ch showed an elevated NE excretion, while Wh's value was low. In this connection it was observed that those fighters who engaged in shadow boxing before the contest had elevated NE excretion rates. From Br, who lost a close decision, only a post-fight sample was obtained. After the contest he had quickly retired to his hotel room and the sample was obtained there. He was found to be quite disappointed, and spontaneously said that the fight was an extremely difficult one which had tired him greatly.

The high NE pre-fight values were noted in fighters who engaged in shadow boxing before the contest. The highest pre-fight E excretions were found in the fighters who showed the greater degree of anticipation preceding the fight. Finally, increase in the post-fight samples over the pre-fight samples of E were observed in those fighters who had to fight for decision in close contests.

Professional Hockey Players. The relationship of the sympathico-adrenal system to the pituitary-adrenal mechanism in the stress responses has attracted considerable attention (6, 9). The present study is concerned with the measurement of the sympathico-adrenal system in terms of the excretion of epinephrine (E) and norepinephrine (NE) and the pituitary-adrenal system with the measurement of 17-hydroxycorticosteroid (17-OHCS) and 17-ketosteroid (17-KS) excretion of professional hockey players and their coach before and after the stressful conditions undergone in this sport event.

Because of the combination of speed and body contact, ice hockey may be considered as one of the more strenuous sports. The athletes are highly proficient in their field and in the peak of physical condition. In addition to the fact that these men are professional athletes, the very nature of the sport itself makes for a highly competitive engagement. The players studied were cooperative and participated in the experiment quite willingly. The age of the players involved ranged from 21 to 33 years; the weights, 170 to 190 pounds; the heights five foot, eight inches to six foot, one inch. These men played the game with other athletes of similar background and competitive nature on a rink 210 feet long and 90 feet wide. The speed of the skaters is estimated at times to be as high as 35 to 45 miles per hour. The skating of the players is at times impeded or stopped by opponents employing body contact, for the most part in accordance with specifically stated rules. In a game of this nature there is frequent display of emotional involvement with high incidence of physical injury.

The urinary excretion of E and NE was measured before and after a regularly scheduled game of the team studied. All urine formed during the contest was used. Urine collections were made in the dressing room from 10 to 30 minutes before the game and 5 to 10 minutes following the completion of the game. The investigator (J. M. H.) present at the games was well known to the players and enjoyed access to the dressing room throughout the season. The players were interviewed in a casual, offhand manner prior to, and at the conclusion of the game. Observations were made as to the player's general status in each instance, as well as the character of the contest. When feasible, direct questions were asked designed to ascertain the individual's feelings before and after the game, as well as to any specific reactions present.

The time consumed in playing a professional hockey game is 60 minutes of actual playing time. The lapsed time from beginning of the game to the

end is about three hours. This 60-minute time limit is divided into three 20-minute periods of active play, with 10 minutes of rest between periods. The games started at 8:30 p.m. and usually terminated at 10:45 p.m. The coach is involved actively in the game throughout the 60 minutes, and for a period of time, at least 10 minutes prior to the game, when he instructs the players as to what type of game he desires them to play. Between periods the coach outlines the strategy and attempts to correct any faults which he may have detected during the play. The goal tender remains the entire 60 minutes of play (except for rare occasions) in front of the net in constant vigilance, ready to protect the goal against opposing players. The defensemen take regular turns on the ice, each playing about 30 minutes. The forwards, consisting of a center, right and left wing (which is the offensive unit of the team) each play 20 to 25 minutes, depending on what transpires in the game.

Data was obtained on 34 players participating in seven games. These games took place from December 4, 1955, through March 5, 1956. Table 2 represents the results obtained from all the subjects studied. It may be noted that no significant changes are apparent in the 17-OHCS and the 17-KS, but significant increases were obtained in the sympathico-adrenal system as measured by the urinary excretion of the E and NE. The NE increased fourfold, while E increased twofold. In Table 3 we have the correlation coefficients of the various indices measured. We note that the only significant correlation is that between E and NE, with an "r" of .48. All other relationships were not significant.

As may be expected, there was considerable variability, depending on the nature of the games played. Two games were quite outstanding. These are the games Nos. 6 and 7. In game 6 the team studied lost by a wide margin; score was 1 to 7. After the first five minutes of that game there was no doubt as to the outcome. Game number 7 was quite unique in that the team studied *had to win* in order to qualify for the finals for the Stanley Cup. This game ended in a tie of 2 to 2. Inspection of the data (Table 4) indicated that when all the skaters (defensemen and forwards) were taken as a single group in games 1 to 5, inclusive, a decrease in the 17-KS was obtained during the game when compared with the control (not significant). However, a significant increase in the 17-OHCS was apparent. Although the increase is small (about 28%) this increase was highly significant. On the other hand, in game 6 (Table 5) where the outcome was not in doubt after the first five minutes, and the team lost by a wide margin, we note that outside of the goal tender, who played during the whole game and did not have an adequate defense or protection, all other subjects of the team samples show a *drop* in the 17-OHCS. The goalie was considerably distressed, showing marked increase in the 17-OHCS excretion. The 17-KS excretion of the players was quite variable. The goalie showed an elevated 17-KS even before the game.

In contrast to game 6, in game 7 (Table 5) all subjects showed increased 17-OHCS. This game, ending in a tie, involved considerable stress. Upon the outcome of this game rested the eligibility of this team to compete for the championship cup.

The correlation coefficient of 17-OHCS vs. 17-KS was .2, and not significant. In Table 6 the data indicate that within the range of 17-KS of 0.0 to .39 mgm./100mgm. creatinine, the 17-OHCS/17-KS ratio was 2.36. This was

a significantly higher ratio than obtained within the range of 17-KS values of .40 to .59 mgm/100 mgm. creatinine, where the ratio was 1.14. Then the 17-KS values were greater than .6 mgm./100 mgm. creatinine, the ration was 0.81 which was significantly lower than the 1.14 obtained in the latter group. These results may be interpreted to mean that with the increased 17-KS excretion there was either an increase in the metabolism of 17-AHCS, or that 17-KS were directly secreted by the adrenal gland. These results were similar to those reported in combat infantrymen in Korea (1).

In Table 7 we observe all the data of the individual players participating in game 5. This game was won by the team studied by a score of 3 to 1. The team had played in three of the previous four nights, and by the third period there was observed a discernible fatigue. The game was bitterly played, and we can observe from data the variability of the results within the game.

Table 8 contains the data of the goal tender and the coach in each of the games sampled. We observed in the goal tender, in game 5, where the team won 3 to 1, an increase in 17-KS, NE, and E, but an actual decrease in the 17-OHCS titer. In game 6 the goal tender was considerably stressed and, as may be noted, the game was lost by the score of 1 to 7. During the interview in the dressing room at the end of the game the goalie was completely exhausted. This was apparent both by his motor activity as well as his verbal expressions. He stated that he was "utterly pooped." This was attested to by the fact that he was too tired to even move. Note that his 17-OHCS, 17-KS, E, and NE values are highly elevated during the post-game sampling. It is of interest to note that his pre-game 17-KS value was very high, quite unlike any of the other samples on this player. In game 7 we note in the goalie an increase in the pituitary-adrenal system both in terms of 17-OHCS and 17-KS, with only moderate elevations in the NE and E excretion rates. He played a brilliant game, but the team was unable to win.

The results on the coach were quite variable from game to game. There was a fair consistency in the 17-OHCS excretion rates. The coach showed an increase in 17-OHCS in all games sampled, except game 6, where the team lost by the one-sided score of 1 to 7. In all the other values there was marked variability from game to game. For NE we note that except for game number 1, where the team won 5 to 0, there were varying degrees of increases. As far as E is concerned in game 4, the coach showed marked increase in E excretion during the game. In game 2 he shows a moderate increase. However, in all other games the coach shows no increase, but a *decrease* in the E excretion rate. The data obtained from the goal tender and the coach indicated quite clearly that when one considers the sympathico-adrenal system and the pituitary-adrenal system in a stress situation, as measured by the indices in this study, each system worked independently of the other. At times both systems are stimulated, and at other times, one or the other, or neither shows increases in stress situations studied.

In addition to the goal tender and the coach, four active players were studied in at least three different games. The data in Table 9 indicate clearly that the variability obtained is dependent, not only on the nature of the game played, but also on the individual differences of each player. Player number 18 shows a degree of consistency in the 17-KS excretion that is worth noting. In each of the games in which he participated, the 17-KS was quite elevated *before* the game. After the game there is a marked *drop*

in the 17-KS excretion. This pattern within the 17-KS output shows no relationship to the three other indices measured. Player number 4 shows a consistent 17-OHCS increase in each game studied. We note marked variability in the excretion of E and NE which may be related to the degree of involvement of the player in the game and to the bitterness of the contest.

Two players were sampled before the game, who, upon examination by the trainer, were considered unfit to play. Both of these players were interviewed, and samples were obtained at the end of the game with the other contestants. In Table 10 it may be observed that little or no increase in NE is apparent in either player, but that both showed marked elevations in E excretion. Each of these players was quite concerned about the nature of the injury and fearful that his professional career might be jeopardized if the injuries did not heal properly and rapidly. In game 4, player 16 was involved in a fist fight and was ordered out of the game by officials. Here again only moderate increases in the pituitary-adrenal system were evident in terms of the 17-OHCS and the 17-KS, while the sympathico-adrenal system showed considerable overactivity when measured in terms of E and NE excretion. The value 3.3 μg/100 mgm creatinine, for E was the highest E value observed in all the subjects.

SUMMARY

Data were presented on the epinephrine (E) and norepinephrine (NE) excretion of amateur boxers, and E and NE excretion as well as the excretion of 17-hydroxycorticosteroid (17-OHCS) and 17-ketosteroid (17-KS) of professional hockey players.

Varying increases in the NE excretion were observed in the amateur boxers, with or without elevated E excretion, depending on the tenseness of the boxer, especially before the contest. Those boxers who engaged in shadow boxing before the contest showed elevated NE.

No significant increases were observed in the 17-KS excretion of professional hockey players. The small increase in 17-OHCS was significant. The most pronounced elevation was in NE excretion with moderate increase in E.

The possible significance of the relation between the biochemical results to the outcome of the game and the incidents occurring during the contest were discussed.

No correlations were observed between the indices of pituitary-adrenal and the sympathico-adrenal systems.

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TABLE 1.

Excretion of epinephrine (E) and norepinephrine (NE) in amateur boxers, as μ/100 mg. creatinine

Boxer		NE μg.	E μg.	Outcome
Ch	pre	17.9	1.64	Winner by decision
	post	......	......	in the third round
Sm	pre	38.1	1.78	Winner by TKO in
	post	32.4	0.67	the third round
Pe	pre	6.7	0.22	Winner by decision
	post	2.8	0.41	in the third round
Br	pre	4.2	0.40	Winner by decision
	post	7.0	0.87	in the third round
Wh	pre	1.7	1.67	Winner by TKO in
	post	......	......	the second round
Bra	pre	......	......	Loser by decision in
	post	15.9	1.70	the third round

TABLE 2.

Data on hockey players, all subjects studied*

	17-OHCS mgm	17-KS mgm	NE μg	E μg
No. of Players	(33)	(25)	(34)	(34)
pre	.53	.52	2.6	.35
post	.63	.49	11.8	.80
sig.	NS	NS	p= <.001	p= <.02

* All data presented as mg per/100 mgm creatinine

TABLE 3.

Hockey players, correlation coefficients (r) between endocrine functions

	N	r	P
E, NE	68	.48	.01
E, 17-KS	54	.20	NS
E, 17-OHCS	67	.05	NS
NE, 17-KS	54	.02	NS
NE, 17-OHCS	67	—.22	NS
17-KS, 17-OHCS	53	.20	NS

TABLE 4.

DATA ON ALL ACTIVE SKATERS IN GAMES 1 TO 5 INCLUSIVE

	17-OHCS mgm	17-KS mgm	NE μg	E μg
No. of Subjects	(15)	(13)	(15)	(15)
pre	.46 ± .02	.55 ± .06	2.6 ± .5	.30 ± .08
post	.59 ± .04	.46 ± .06	13.1 ± 1.9	.76 ± .25
sig.	p < .01	NS	p < .01	p <.05

TABLE 5.

STEROID EXCRETION

Game #6 (lost 1 to 7)

			17-OHCS mgm	17-KS mgm
#1	Goal Tender	pre	.59	1.06
		post	1.01	.87
#15	Coach	pre	.58	.33
		post	.27	.22
#12	Skaters	pre	1.24	.90
		post	.51	......
#14	"	pre	.59	.23
		post	.45	......
#17	"	pre	.68	1.22
		post	.45	.82
		Game #7 (tie 2 to 2)		
#1	Goal Tender	pre	.48	.23
		post	1.19	.80
#15	Coach	pre	.37	......
		post	.43	......
#4	Skaters	pre	.48	.24
		post	1.03	.21
#14	"	pre	.29	......
		post	1.23	......
#17	"	pre	.47	.52
		post	.74	.34

TABLE 6.

THE 17-OHCS : 17-KS RATIO

	17-KS	N	17-OHCS / 17-KS
I.	0 — .39	21	2.36 ± .23
II.	.40 — .59	15	1.14 ± .08
III.	.60 or greater	17	.81 ± .07

Sig.: I, II; II, III; both with p.01

TABLE 7.

DATA OF GAME #5*

Player No.		17-OHCS mgm	17-KS mgm	NE µg	E µg
#1	pre	.58	.21	4.3	.21
	post	.34	.34	9.1	.57
#15 Coach	pre	.52	.21	1.6	.28
	post	.63	.35	5.1	.12
#8	pre	.53	.93	6.7	.34
	post	.53	.32	20.1	1.17
#4	pre	.43	.43	.5	.41
	post	.81	1.13	16.4	1.43
#14	pre	.43	.17	1.6	1.25
	post	.51	.34	5.1	1.40
#20	pre	1.01	.52	1.0	.94
	post	.47	.43	18.5	1.80

* All data in terms of 100 mgm creatinine

Remarks — Won 3-1 (bitterly played). Three games in four nights; fatigue in third period.

TABLE 8.

GOAL TENDER*

		17-OHCS mgm	17-KS mgm	NE µg	E µg
Game #5 (won 3-1)	pre	.58	.21	4.3	.21
	post	.34	.34	9.1	.57
Game #6 (lost 1-7)	pre	.59	1.06	3.7	.84
	post	1.01	.87	12.3	2.11
Game #7 (tie 2-2)	pre	.48	.23	2.0	.29
	post	1.19	.80	6.2	.43
		COACH			
Game #1 (won 5-0)	pre	.49	....	2.1	.51
	post	.54	....	1.1	.21
Game #2 (won 4-1)	pre	.63	.13	0.5	.51
	post	.80	.25	1.4	.86
Game #4 (won 3-1)	pre	.50	....	4.1	.64
	post	.80	....	4.9	1.29
Game #5 (won 3-1)	pre	.52	.21	1.6	.28
	post	.63	.35	5.1	.12
Game #6 (lost 1-7)	pre	.58	.33	0.9	.04
	post	.27	.22	4.2	.04
Game #7 (tie 2-2)	pre	.37	....	1.3	.24
	post	.43	....	3.9	.08

* All data in terms of 100 mgm creatinine

TABLE 9*

FOUR ACTIVE PLAYERS STUDIED IN 3 GAMES

	Game #		17-OHCS mgm	17-KS mgm	NE µg	E µg
Player No. 8	1	pre	.54	.94	3.9	.10
		post	.60	.38	16.4	.22
	2	pre	.40	.71	0.7	.14
		post	.36	.18	3.1	.13
	5	pre	.53	.93	0.7	.34
		post	.53	.32	20.7	1.17
Player No. 14	5	pre	.43	.17	0.5	1.25
		post	.51	.34	16.4	1.40
	6	pre	.59	.23	5.4	.20
		post	.45	...	17.3	.54
	7	pre	.29	....	1.3	.13
		post	1.23	....	16.3	.12
Player No. 4	3	pre	.49	.65	1.1	.32
		post	.70	.57	3.8	.18
	5	pre	.43	.43	0.7	.41
		post	.81	1.13	20.1	1.43
	7	pre	.48	.24	3.1	.02
		post	1.03	.21	7.3	.04
Player No. 10	2	pre	.48	.17	1.1	.06
		post	.61	.17	9.0	.05
	3	pre	.42	.49	1.6	.13
		post	.42	.43	5.9	.35
	4**	pre	.76	.82	5.6	.78
		post	.44	.70	5.3	1.42

* All data in terms of 100 mgm creatinine

** Injured; not allowed to play

TABLE 10*

DATA OF INTEREST: MISCELLANEOUS

	Player No.		17-OHCS mgm	17-KS mgm	NE µg	E µg
Game #3	18	pre	.41	.40	2.2	.23
		post	.49	.50	3.3	.75
Game #4	10	pre	.76	.82	5.6	.78
		post	.44	.70	5.3	1.42
Game #4	16	pre	.35	.35	3.5	.18
		post	.46	.47	29.3	3.30

* All data in terms of 100 mgm creatinine

GENERAL DISCUSSION ON
APPLICATION OF STANDARD WORK TESTS

LEE: The subject is now open for discussion.

LT. BILLY WELCH: (*Medical Nutrition Lab.*) A lot of these so-called standard tests apparently are sufficient to distinguish between the obese, middle-aged individual and the younger, athletic men. In our tests we get uniformly as test subjects rather young and reasonably well-conditioned people. With this particular group we have experienced some difficulty in correlating the standard laboratory tests with each other. For example, the maximal oxygen consumption, when expressed in liters per minute, is a measure of cardiovascular efficiency. One would think that it should correlate very highly with the step test, which is another measure of cardiovascular efficiency, but we do not find this to be the case. We have made an effort to bring together a group of tests that measure functions ranging from eye-hand coordination and agility to cardiovascular fitness, with the idea of coming out with something rather simple, if possible, that could be applied rather widely in the field by, say, relatively inexperienced investigators. We have not been successful up to this point. I realize I have said much about nothing, but that is where we stand. We plan to do additional work in which we will hope to come up with a battery of tests, or a test, that we can use to fulfill the idea of a work index.

BUSKIRK: It may not be surprising to find that the correlation between the "maximal oxygen intake" and the Harvard Fitness Test Score (step version) is rather low. As I understand D. Welch's use of the Harvard Fitness Test (step version), he uses a fixed stepping time of three minutes. The sum of the recovery pulse rates for those who cannot keep up for three minutes is adjusted by appropriate regression equations. Thus, the Harvard Fitness Test Score, when the test is used in this way, is dependent only on the pulse rate response to stepping. Stepping (16-inch bench) of course, is a different activity from running on a treadmill and its demands may not be close to the subject's "true" working capacity for running. The relationship between the Harvard Fitness Test Score and the "maximal oxygen intake" becomes then essentially the relationship between the pulse rate response to stepping and the "maximal oxygen intake" during running. Since many more factors contribute to the maximal oxygen intake than the rate of heart contraction at one rate of work, expectation of a high correlation may not be justified.

Of interest in this context is the correlation found by K. Lange Andersen between the conventional Harvard Fitness Test Score (treadmill version) and the maximal oxygen intake in a group of young soldiers who were participating in the studies carried out at the Laboratory of Physiological Hygiene. The coefficient of correlation was 0.70. In this instance the men ran to exhaustion or for five minutes, whichever occurred first. Assuming motivation for running was not a factor (dubious), the greater magnitude of the correlation in comparison to Dr. Welch's experience (no value cited) may reflect the difference in severity of the work performed. In other words, the conditions for the treadmill Harvard Fitness Test and maximal oxygen intake are close to work limits, while stepping for three minutes up a 16-inch step is not.

GROSSMAN: I have a few general remarks to make on the application of

standard work tests in the field. The distinction between field tests and laboratory tests is like the distinction we often make between clinical and laboratory studies or the distinction between applied and basic research. The lines of demarcation are not always easy to find. The tests that can be performed in the field are essentially the same ones that are performed in the laboratory. I don't think any tests have been referred to here that cannot be applied under field conditions. We have treadmills on wheels; we have all of the equipment for measuring all the physiological parameters that have been referred to, and these can all be done in the field. The same general types of parameters would be used, such as pulse rate, body temperature, duration of running, and so on. When we designate a topic like "Application of Standard Work Tests in the Field," we usually mean the use of tests which would not be used in the laboratory but possibly could be used in combination with laboratory measurements such as taking a group of soldiers out on a hike and using this as a test. The only important distinction in my mind is that when tests are applied under circumstances in which the reproducibility of the environmental circumstances is not as great as it would be in the laboratory, then the important use that we can make of such tests is the comparison of groups that are simultaneously exposed to the field conditions rather than getting "absolute values."

BUSKIRK: I concur wholeheartedly with Dr. Grossman. When most of us go into the field, the first thing we do is to set up a laboratory. There are certain exceptions to this, as we have heard already this morning. Dr. LeBlanc, for example, followed people who were pulling sleds. Others of us have collected air samples from men engaged in other real-life activities. I would like to digress from the rugged experimental approach and cite specific examples of transfer of procedures from laboratory to the field. Many of you know much more about this than I do, and perhaps you will comment a little later. The predicted four-hour sweat rate of McCardle, for example, is one measurement that is usable both in the field and in the laboratory. For the most part, this index has proved of value in the field, although the prediction of sweat rates is not nearly as good as it is in the laboratory, where environmental conditions can be standardized much more adequately and precisely. In athletics, the "field" refers to the field of performance, and "performance" is the specific athletic event during competition. Roger Bannister (the mile runner) perhaps has set a good example for others with his application of transfer of training from the laboratory to the athletic field. It is said that he gained confidence for running the four-minute mile in the laboratory. He measured his oxygen consumption, ventilation, and a number of other measurements at various running speeds on the treadmill and found that the four-minute mile should be within his grasp. He convinced himself of this. Then, through field trials on the track, during which time he tested the laboratory findings, he toiled toward his goal of the four-minute mile. He also spent some time at higher altitudes. Dr. Balke has mentioned this. We all know how successful he was in this transfer since he reached his goal, the four-minute mile.

The synthesis of the whole laboratory-field problem will be closer to solution if we allow the man to do his work in the field and allow the investigator to stay in the laboratory.

I believe we all concur that performance in some athletic events is truly amazing. Dr. Elmadjian has indicated that the degree of strain on these individuals seems to be quite marked. I would like to say just a few

words about another athletic event, to point up the severity of exertion that some people are willing to undergo and the peak efforts they will put forth. Running a marathon, for example, 26 plus miles in slightly over two hours at a pace of 11 plus miles per hour is truly an amazing feat — yet there are a good many people who can do this. Most of us sitting in this room can't run ten miles an hour for even one minute. Not only is the pace amazing, but the motivation to continue is something that I, at least, can't fully grasp. Of course the true strain on these marathoners has not been adequately assessed. Some seemingly finish a race in reasonably good condition. However, even the best runners maintain that they are stiff and sore for a day or more after a race, and urine samples indicate that a reasonable question might be: "What was the hematocrit of the runner's urine?" Heart rates might not be considered abnormal at all at the end of a race, but systolic pressure may fall to fairly low levels while diastolic pressure varies all over the place — in fact, it can be elevated or markedly depressed so that the pulse pressure, say, may be no more than 10 to 15 mm of mercury, or it can be as high as 100 mm. Of course this is probably an artifact of the systems. The runner may finish with a rectal temperature no higher than 102° F. or 103° F., yet the runner has lost from 3 to 5 kg. of body weight and must be considered acutely dehydrated. Many marathon runners apparently undergo shifts in temperature regulation during the course of a race. Chills 12 to 18 miles out on the road are a common complaint and a source of apprehension to the runners. Diarrhea, nausea, and vomiting are not at all uncommon. The diarrhea, at least, I am told, is frequently preceded by staccato elimination of flatus, which is most disconcerting to these runners. Actually, when this happens they feel they have "had it." Superior performance in most other athletic events involves considerable skill, so it is a complex situation rather than one involving only fitness or endurance capabilities. In these latter events that I have mentioned, skill complicates immeasurably the physiological study of athletic performance.

VOGEL: We happen to be particularly fortunate, in the Submarine Service, in that we can conduct certain field studies under controlled conditions. We are in a closed tube, where we can measure temperature, humidity, oxygen concentration, carbon dioxide presence, and the presence of other gases as well as having a laboratory aboard the submarine. This makes for a very fine setup for field studies. We have made determinations on caloric requirements of people aboard submarines under varying conditions, and we have a clear picture of what the oxygen consumption and carbon dioxide output are under these conditions. Of course it is impossible to put a submarine into any sort of jeopardy just for the sake of our field trials. But we are fortunate in having a real stress situation in our escape training tank, where we can conduct various experiments in the field under true stress conditions, with no artificiality whatsoever.

BASS: I would like to ask Dr. Elmadjian a question, if I may. In connection with the creatinine excretion which you used as a baseline, did you have any idea of its variability?

ELMADJIAN: I will explain how we did it, Dr. Bass. In the pretesting, the timing was very difficult, but during the test we had accurate time samples. In other words, we got a sample ten minutes before the game and at the end of the game, and we got all the urine from these people. Then what happened was that each individual, at some time, did contribute to us a controlled sample so that we knew whether or not he had an increase in

creatinine. There was no significant increase in creatinine excretion.

BASS: How about decrease?

ELMADJIAN: No decrease. These people went very nicely by the formula given in classical text books that there is a certain creatinine coefficient of something like 26 to 32 for males who have a certain muscle mass — and we calculated the muscle mass of these gentlemen because we felt that if anyone was really hard, packed with no excess fat, these were the men. They did fit the curve as far as their creatinine was concerned. The boys who weighed 160 or 175 pounds had lower creatinine than the 200-pounders. It went right along that curve, as stated in Peters and Van Slyke's chapter on creatinine.

GRAY: I would like to bring up a point that I believe all of us realize but haven't talked about today. As far as the Army is concerned, yes, we want to know man's *maximal* performance capacity. But it doesn't do us very much good if the infantryman has moved into position completely exhausted. The problem of *optimal* performance, so that this man can get up there and do his job and then respond adequately to a wound, for example, is one which is quite pertinent and which I don't believe has been touched on in the comments made so far at this meeting. It is something that is quite critical and is something that needs an awful lot of thought in order to really assess what these men can do. I simply want to point this out. On this basis, the requirements of the Navy and Air Force are somewhat different from the requirements of the Army.

LEE: I would like to explore that a little bit in a somewhat different fashion. Of equal importance to the Army on many occasions, or to any Service, would be not the performance capacity but what it costs the man to do what he has to do. The cost in the end may be more important than the particular ceiling he can reach.

SMITH: I would like to comment and add to Colonel Gray's statements a comment, not from the standpoint of the Military, but with reference to the whole concept of the science of work and our duties in regard to the lifelong behavior and welfare of individuals. The significant problems are not the extraordinary stresses — the dramatic demands — but equally there are the problems of "maintenance" — of devising conditions which will support the individual effectively and even happily throughout the course of his life. I don't view the military situation as essentially different from, let's say, the man on the assembly line. He isn't only going to work an hour or two — he is going to work 40 years. The stresses, if they occur, and as we see them occur in the dramatic situations, may have equally important extrapolated effects when taken in small amounts over a long period of time. I would like to suggest that in discussing these matters we look more to the problems of work situations and equipment which will, over a lifetime, make the best use of the human body as a physiological and psychological system rather than focus on the selection of those few extraordinary individuals who can run the four-minute mile or who can stay on the treadmill longest. Our tough but important problems are the problems of work from the standpoint of the design of physical environment, man-operated machines, man's clothes, or devices and tools, which will provide not only quick efficiency under brief duress but a lifelong adaptation that is in keeping with the general medical and social welfare of the individual. To the extent that this conference achieves a better understanding of the long-term stress

problem, it will have done its duty to better define the critical conditions of human work. Over the last 40 years we have had repeated approaches to the problem of dramatic stress — heat, cold, maximal athletic performance. But these approaches have not solved the crucial questions of creating better work environments. There is much work yet to be done in the field of dramatic stresses, but I am sure that the problems that are troubling many of the people around this table are not these dramatic problems but the lifelong adaptation problems — what will happen when the soldier has to keep up a task for two or four years? I believe that problem is possibly closer to the total welfare of the Army than the problem of the quick-running guy who shows or who does not show marked increases in heart rate.

CLARK: (*School of Aviation Medicine, Brooks Air Force Base*) I want to say a few words in regard to the Air Force. I agree entirely with Dr. Smith. We are interested not only in the man who can get out and fly a jet plane 1100 miles an hour — that is one man and we are interested in him, of course — but we want to let each individual — the secretary, the man behind the desk, the man at the Pentagon, the man anywhere — live a long, productive life span. Here are some aspects of our work. We start at the tissue level. We are doing experiments now on mitochondria, on the transaminases, tissue trauma, on animals. Secondly, we are running chemical analyses on the human, on his every aspect: the cholesterol changes during extreme work, amino acid changes, glucose, lactic acid, ketone bodies, and so on. These are some things we are measuring during physical work.

Now, some varied conditions that Dr. Smith might be interested in: We have some problems that I think are different from those met in the Army and in the Submarine Service. Consider the individual who flies a propeller-type airplane and is doing fine. But when he steps into a jet aircraft, that's something else again. What happens, gentlemen? We have some quantitative data. Over 50 percent of the people who step into an aircraft of the jet type will hyperventilate, due to anxiety, shifting from a normal level of around 37 to 40 mm pCO_2 down to as low as 18 or 19 mm, which will produce cardiospasm in the laboratory. The individuals vary, depending on whether they are engaged in formation flying, night flying, soloing, and so on. We have in-flight measurements of all that is going on. The men will hyperventilate according to the performance of the aircraft. The higher the performance of the aircraft, the more they tend to hyperventilate, regardless of whether or not they are students. The pH is around 7.6 or 7.7, but they are able to fly the aircraft as well as the next pilot. Dr. Wells and Dr. Balke have checked on this day in and day out. That is one example that probably you don't bump into very frequently. The hypoglycemia that develops when they step into the aircraft is another problem. Dr. Elmadjian's data will help us out a lot. It all boils down to the fact that that is one type of work situation. The man at the Pentagon represents another situation. We want to fit all of them together and enable everybody to live a long, happy life.

SARGENT: I have been working, on contract, for the Air Force for five years. We have been particularly concerned with the fellow who goes down with the aircraft and survives — the castaway. Both Dr. Johnson and I would like to go on record to the effect that we are very disturbed that the military forces are not sufficiently interested in the injured castaway. I was very happy to hear Colonel Gray say he is interested in the injured soldier. Most of the men are probably going to get hurt to some extent when the airplane

crashes. All our thinking and planning and survival rations are based on the normal young man — who is normal at the beginning and fairly normal at at the end, who isn't injured, who doesn't have any broken bones. The nutritional requirements for him are different for the injured man, we know, and the effects of heat and cold are going to be different. I would put in a plea that the Armed Forces begin to think more about the injured castaway. After all, we have $50,000 (or is it $250,000?) invested in the training of each of these pilots. These men are just as important to recover and bring back as are the healthy castaways.

VOGEL: In that connection, I would like to point to a report that has just come out from the operation DEEPFREEZE I.* It gives some of the medical and dental data obtained during that operation, including some of the things Dr. Sargent just questioned, where these people did crash and went into shock from very minor injuries, and all the rest, and what their survival rations were like, and what they were capable of doing. It is a very interesting and illuminating report. I commend it to all of you.

SPECTOR: Because of the very nature of the stress and the severity of it, we are forced at times to resort to animal experimentation. I feel that we really haven't gotten the most out of our conference today if we don't give some attention to the relationship or the extrapolation of animal studies to man. I think most of us are primarily concerned, in this area, with what happens to man. We use animals as a research tool. I would like to hear some discussion directed to these matters. Perhaps Dr. Balke would start the ball rolling. I know he has done both and has made such correlations.

BALKE: I like to work with humans rather than animals. You have to work with animals if you have to, but all the studies we can do on humans I prefer to do on humans.

SPECTOR: I would agree that, with humans, many things are a lot easier to do. You have a cooperative subject. But when you do use your animals, do you find that they follow generally the same pattern of responses that you get in man — that they are a valid basis for extrapolation to man?

BALKE: I would say there is a very close correlation between the results obtained by the same testing procedures used on humans and on dogs. For instance, in regard to the pulse rate, the dog has the same critical end point at about 180 pulse. A human can occasionally go up to 210 or 220 beats per minute. However, the physiological limit is about 180, because there we get the crossing of inputs and outputs. In the dog we get a tremendous increase in ventilation, a fall in blood pressure, and so on. Secondly, the oxygen intake per kilogram in the dog is almost the same as in humans or just a little bit more — I don't know why. Maybe it is because they are working on four legs instead of two. I see a very nice relationship between the responses of man and dogs.

SPECTOR: The material that Dr. Young presented shows the same thing. I was wondering whether there are other people here who have experience in correlating animal work with human work?

JOHNSON: I would like to quote from paragraph 2 of Lecture 1 from our course in Comparative Physiology: "When two animals solve the same problem, the only way you can find out that they solve it in the same way is to study the two animals. Extrapolating from any animal experiment is fallacious and misleading unless you have proved that the two animals reacted in the same way."

*Effects of Antarctic Environment on Operations in the Ross Sea Region. Commander in Chief, U. S. Atlantic Fleet, Chief of Naval Operations, 1955-1956.

LEE: Anybody doing work with heat regulation knows that extrapolation is extremely dangerous.

CRAIG: In the Chemical Corps we are unfortunate in that we can't determine the lethal doses in man. We have to determine LD_{50}'s for a particular lethal agent in dogs, and we have to guess what will happen in man on the basis of mild exposure. There is considerable debate about some of our figures right now, and we have to hope we are right. But we have no absolute way of proving we are right on some of these things.

JOHNSON: Nobody can debate with you. You have to do it. I know you are aware that you can get into some awful difficulties, like giving a dose of morphine to a cat and a dog. Those are two different things.

BASS: This talk about extrapolation enables me to make my comment to Dr. Clark. The point Dr. Clark made about the hyperventilating pilot going into respiratory alkylosis should be well noted because the pilot shows he can live with it. However, suppose a radar watcher were to go into the same type of alkylosis? How would his efficiency be affected?

CLARK: We are going to study the radar watchers. We have circumstantial evidence to indicate that he does hyperventilate. The important factor is the factor of adaptation. Dr. Wells and Dr. Balke hyperventilated in the laboratory an hour a day for two weeks. They got down to pCO_2 as low as 8 mm and they were able to perform the usual psychomotor tests and other measurements. They became adapted to it over a period of time. Evidently that is what the pilots have done. However, we have too many young pilots who have heart attacks flying an aircraft, too.

VOGEL: I should think that in the long-range studies you propose regarding the requirements for living a full life you would have to relegate a great deal of that to animal studies, because man's usual life span is much longer.

CLARK: That is true. We have a group of rats and, as Dr. Lee said, with heat they don't do so well. But we try to work with an animal with a life span of about three years compared to man's 60, and then we expose the animal to different life situations. If we do find changes, we will go to another specie and then another, and if we find consistent changes we will try looking for them in the man. You have to start somewhere.

IV. EFFECT OF ENVIRONMENTAL STRESSES ON PERFORMANCE CAPACITY

OPENING REMARKS

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The final session of the conference will be devoted to a consideration of the effect of environmental stresses on performance capacity. Actually, we shall be concerned with the *tests* rather than with the *effects* themselves. We are interested to learn whether the tests that we have available now are adequate, which are the most useful, what their limitations are, and what is needed to give us a better understanding and a better appreciation of the effects of stresses. We are not interested, solely, in measuring performance itself. We are concerned also with the problem of "reserves" and the possibility of an impending collapse of homeostatic mechanisms.

Frequently, a man can *perform* a certain job, but he does so at a considerable physiological expense. There is also a psychological effect. One can see this point more clearly, perhaps, by means of an analogy. You have a full tank of gasoline in your car. You can go 80 miles an hour and get 12 miles to the gallon. You can get 12 miles to the gallon when the tank is full, and you can also get it when you are down to one gallon in the tank. Some of us become much concerned, as the distance stretches out, about the amount of gasoline left in the tank and seek to estimate when we are going to run out. In the human being it is difficult to determine the available reserves. Nevertheless, it is the kind of information we need.

*Deceased, August 14, 1959.

HEAT TOLERANCE AND DEHYDRATION*

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This morning I described a test of heat tolerance which Dr. Johnson and I developed for use in a field study of survival rations. We employed this test at Camp Atterbury, Indiana, in June and July 1955, in order to measure the castaway's capacity for performing a certain fixed workload in the heat. This test was carried out five times on each of 100 volunteer subjects.

The weather. During the 36-day period of the field trial, we had a rather severe heat wave (figure 1). The weather was cool during the first week, but in the succeeding days the daily maximum temperature usually exceeded 90° F. and the minimum temperature averaged in the high 60's.

Periods of study and diets. There were three periods in the study. In the pre-experimental period of 14 days, 88 subjects did moderate work, subsisted on 5-in-1 Rations, and drank unlimited amounts of water. The other 12 men subsisted on a diet of fresh and frozen foods (Field Ration A or FRA) and drank water *ad libitum*. In the 10-day experimental period, the 88 men were divided into four groups. Two groups marched 12 miles a day (hard work) and two marched three miles a day (light work). One hard-work and one light-work group was allowed water *ad libitum;* the other hard- and light-work groups were allowed only one canteen (900 ml) per man day. Within each of the four groups, two to four men subsisted on a variety which ranged in caloric intake from zero to 3000 cal/day and contained four different distributions of calories among protein, carbohydrate, and fat. The FRA subjects continued to eat fresh and frozen foods and drink unlimited amounts of water. In the recovery period, which lasted 12 days, the 88 men again subsisted on 5-in-1 rations and water *ad libitum* and the FRA's continued the diet of previous periods.

Definitions and calculations. Before considering the results of this heat tolerance test, there are two concepts we must clarify (figure 2). The "heat acclimatization test" was patterned after a test developed by W. S. S. Ladell (1) for group assessment of acclimatization, and we have followed his terminology in evaluating our observations.

It is well known that there is a statistical relationship between sweat rate and body weight. We observed such a relationship in our data (2). In order to reduce the individual variability of sweat rates of men working simultaneously under the same ambient conditions of weather, we corrected the observed sweat rates to those which would have occurred if the man had weighed 65 kg. This sweat rate was called the corrected sweat rate (C. S. R.).

In acclimatization to heat, men begin to sweat at lower and lower rectal temperatures or, at the same rectal temperature, acclimatized men sweat at a greater rate than unacclimatized men. The acclimatization index of Ladell is based on these physiological facts. We calculated the acclima-

*The work described here was supported by USAF Contract AF 18(600)-80.

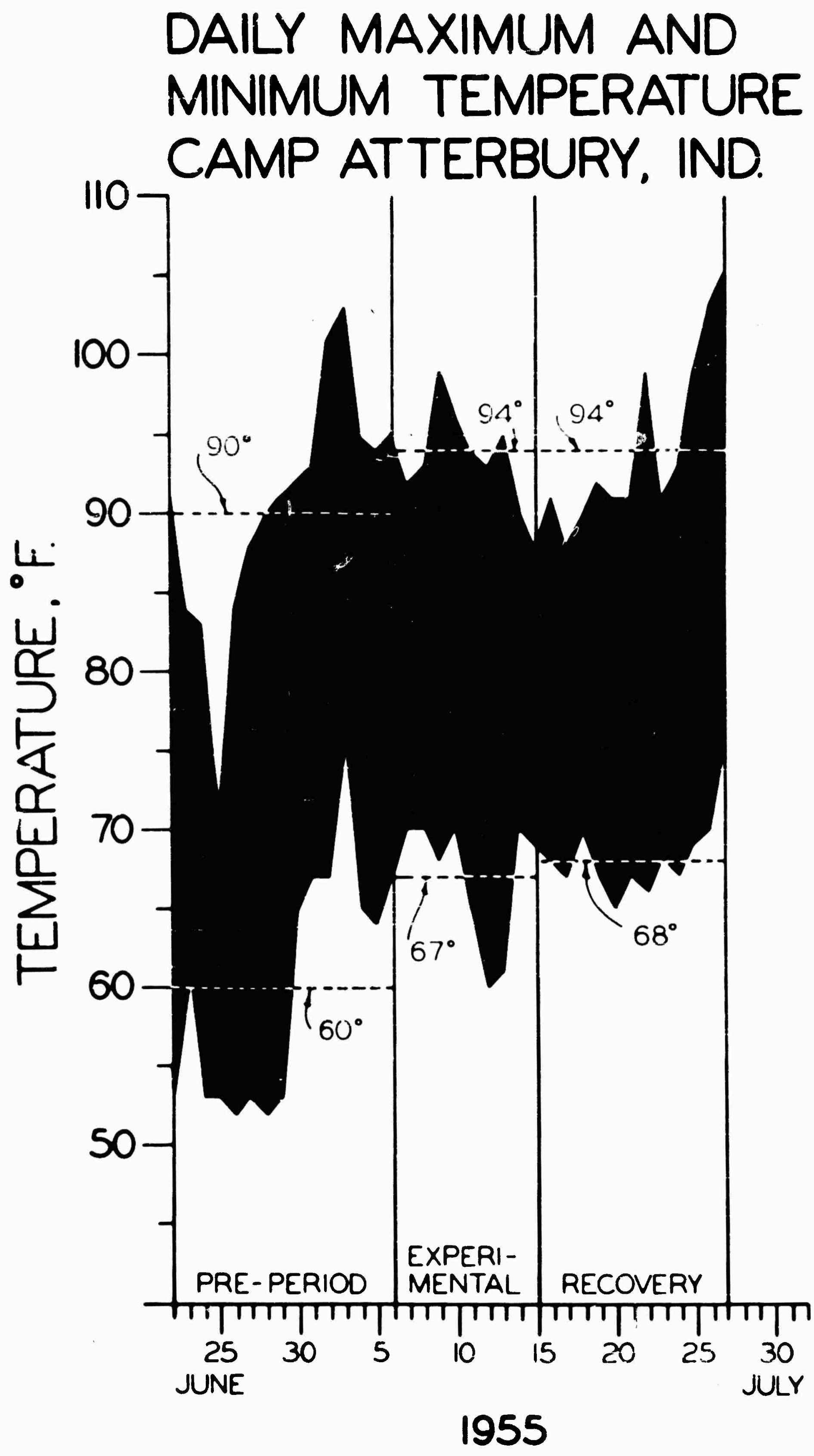

DAILY MAXIMUM AND
MINIMUM TEMPERATURE
CAMP ATTERBURY, IND.
110
100
90
80
70
60
50
TEMPERATURE, °F.
90°
94°
94°
67°
68°
60°
PRE-PERIOD
EXPERI-
MENTAL
RECOVERY
25
30
5
10
15
20
25
30
JUNE
JULY
1955

Figure 1

MATHEMATICAL CALCULATIONS IN HEAT ACCLIMATIZATION TEST

(1) Corrected Sweat Rate (C.S.R.)

$$\text{C.S.R. (ml/hr)} = \frac{\text{Observed Sweat Rate (ml/hr)}}{\text{Body Weight (kg)}} \times 65\,\text{kg}$$

(2) Acclimatization Index (A.I.)

$$\text{A.I. (ml/°F)} = \frac{\text{Corrected Sweat Rate (ml/hr)}}{\text{Increment of Rectal Temperature (°F)}}$$

Figure 2

tization index (A. I.) by dividing the C. S. R. by the increment of rectal temperature for the period of sweat collection. An increasing index indicates development of acclimatization; a decreasing index suggests breakdown of acclimatization.

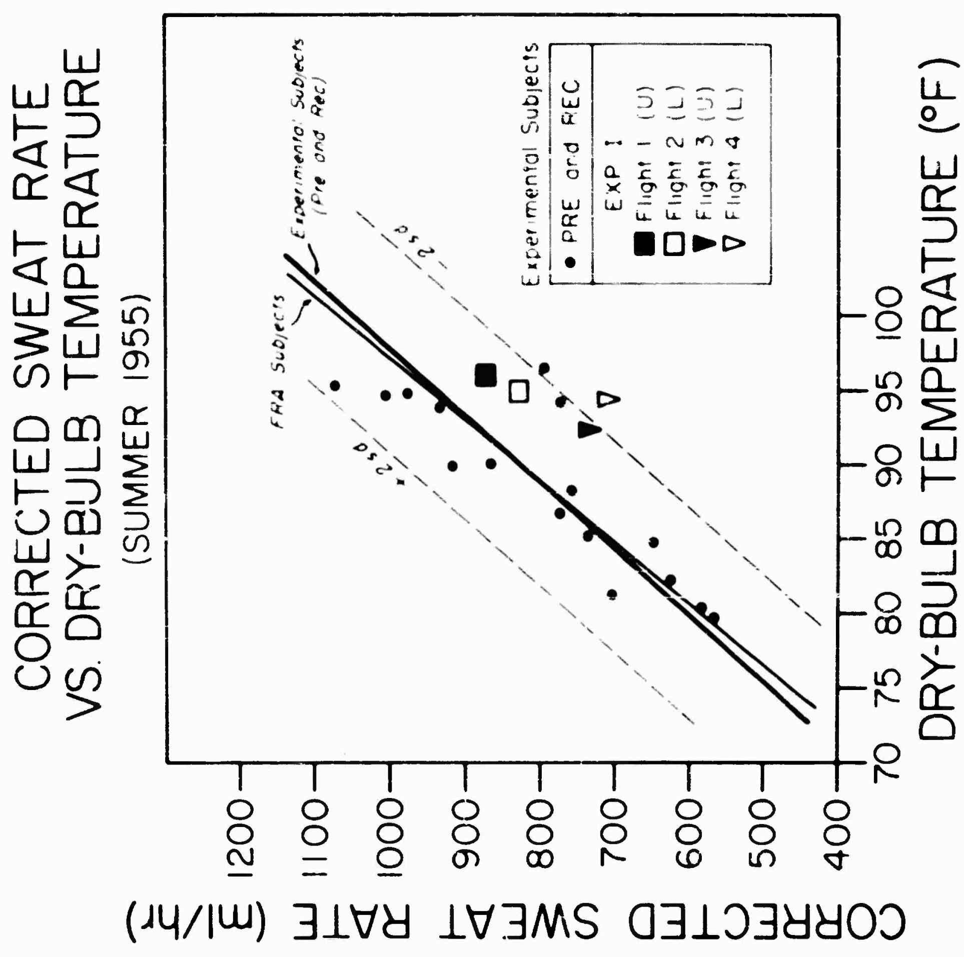
Corrected sweat rate. The corrected sweat rate was linearly related to the ambient temperature. We found statistically significant correlations between C. S. R. and dry bulb temperatures, wet bulb temperature, and effective temperature, but, for present purposes, it will suffice to deal only with dry bulb temperature (figure 3). The two regression lines shown were calculated by the method of least squares. The thin line is for the FRA subjects in all periods; the broad line is for the experimental subjects in the pre experimental and recovery periods only. The points represent the mean sweat rates for groups of 22 men. It is evident that the subjects on 5-in-1 Rations did not have C. S. R.'s significantly different from those of ideal controls (FRA). During the experimental period, when some of the subjects were on restricted water intake and others were on unlimited water, the C. S. R. values declined and approached two standard deviations from the control regression line. Men on restricted water, moreover, deviated just as much as those on unlimited intake of water. The C. S. R. thus was not discriminatory.

Acclimatization index. Men on restricted water had greater increments of rectal temperature during the 3.75-mile walk than men on unrestricted water. When the acclimatization index was calculated, we found that subjects on limited water intake were now separated by two standard deviations from those on unlimited water intake (figure 4). Thus water restriction led to marked deterioration. The decrease in the acclimatization index was statistically significant.

The dry bulb temperatures during the times of testing the four groups in the experimental period were very similar. Furthermore, the temperatures during the second week of the pre-exprimental period and the first week of the experimental period differed by only 0.1° F. in the case of groups with limited water intake. Thus no correction had to be made for the effect of temperature, and a simple "t" test could be applied.

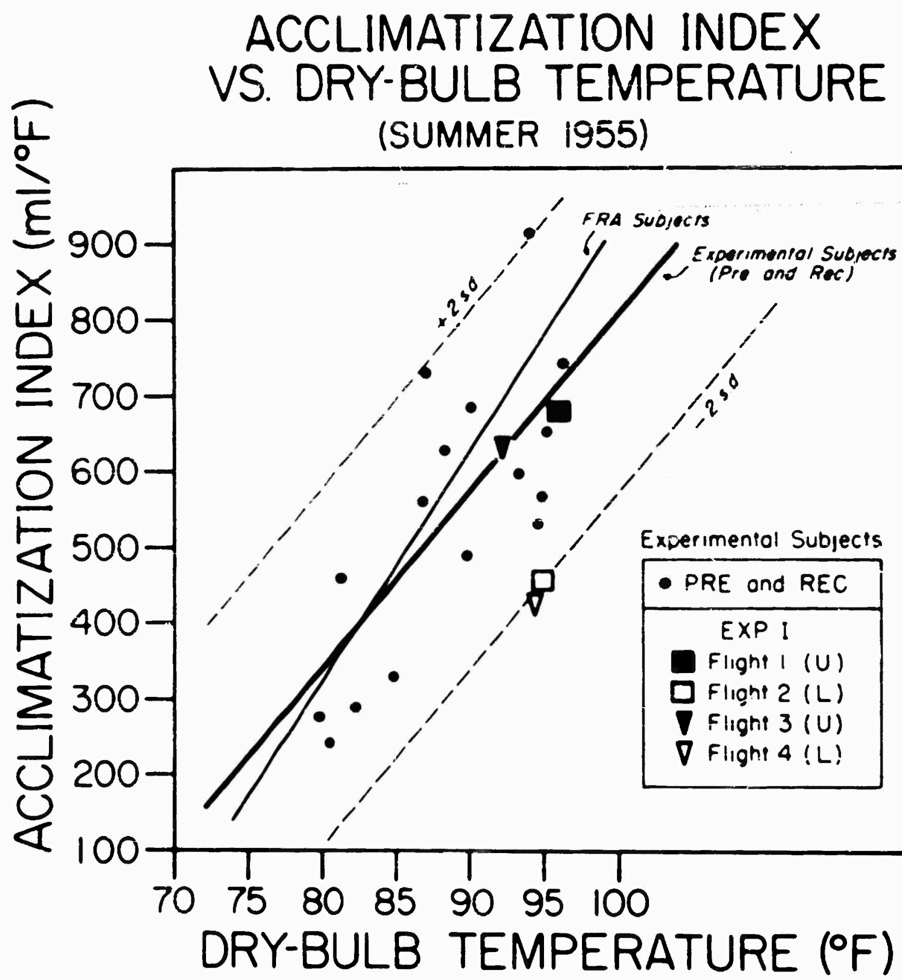
Clinical observations. Without observations on the clinical condition of the subjects, these alterations in sweat rate and rectal temperature would be only of academic interest. Actually, we observed clinical deterioration, too. Four men collapsed while undergoing the heat-tolerance test in the experimental period. One subject had been starving and drinking unlimited amounts of water. The other three had been subsisting on meat bar (pemmican) and restricted water allowance. No man collapsed who had been eating a diet which provided 15 percent of the calories from protein, 33 percent from fat, and 52 percent from carbohydrate.

During the first seven days of the experimental period, other evidence accrued concerning the probable minimum water requirements of the castaway exposed to moist heat. Three subjects developed total anhidrosis, and eight developed clinically significant hypohidrosis. Among the latter there was anhidrosis over large areas of the body, and they were wet only in small areas such as groin and axilla. At the same time observers were sweating profusely. None of these subjects had miliarial lesions, and none exhibited hyperpyrexia. All, however, had been subsisting on restricted water. Every one of these 11 men who developed clinical disturbance of



CORRECTED SWEAT RATE
VS. DRY-BULB TEMPERATURE
(SUMMER 1955)
FRA Subjects
Experimental Subjects (Pre and Rec)
2 sd
2 sd
Experimental Subjects
PRE and REC
EXP I
Flight 1 (U)
Flight 2 (L)
Flight 3 (U)
Flight 4 (L)
70
75
80
85
90
95
100
DRY-BULB TEMPERATURE (°F)
1200
1100
1000
900
800
700
600
500
400
CORRECTED SWEAT RATE (ml/hr)

Figure 3



ACCLIMATIZATION INDEX
VS. DRY-BULB TEMPERATURE
(SUMMER 1955)
ACCLIMATIZATION INDEX (ml/°F)
900
800
700
600
500
400
300
200
100
70
75
80
85
90
95
100
DRY-BULB TEMPERATURE (°F)
FRA Subjects
Experimental Subjects (Pre and Rec)
+2 sd
-2 sd
Experimental Subjects
PRE and REC
EXP I
Flight 1 (U)
Flight 2 (L)
Flight 3 (U)
Flight 4 (L)

Figure 4

sweating had been eating either nothing (starvation) or pemmican, crackers and oleomargarine, or pure carbohydrate. Not a single subject who was subsisting on a ration which provided 15 percent of the calories from protein, 33 percent from fat, and 52 percent from carbohydrate developed either hypohidrosis or anhidrosis. These clinical observations agree strikingly with the experimental results depicted in figure 4. They strongly support the holistic philosophy we have used in our studies of survival rations. When anhidrosis made its appearance among our subjects, we began to increase the water allowance.We found that 2700 ml of water per day prevented any new disturbances of sweating among men marching 12 miles per day, and 1800 ml of water acted likewise for men marching three miles per day. We conclude that these values represent minimal water requirements for the castaway exposed to moist heat. Less water is dangerous, for the subjects may develop significant reduction in rate of sweating. The final consequences may well be heat stroke.

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SOME GENERALIZATIONS ON CALORIC, WATER, AND OSMOTIC REQUIREMENTS IN THE HEAT AND COLD AS ESTABLISHED IN FIELD STUDIES*

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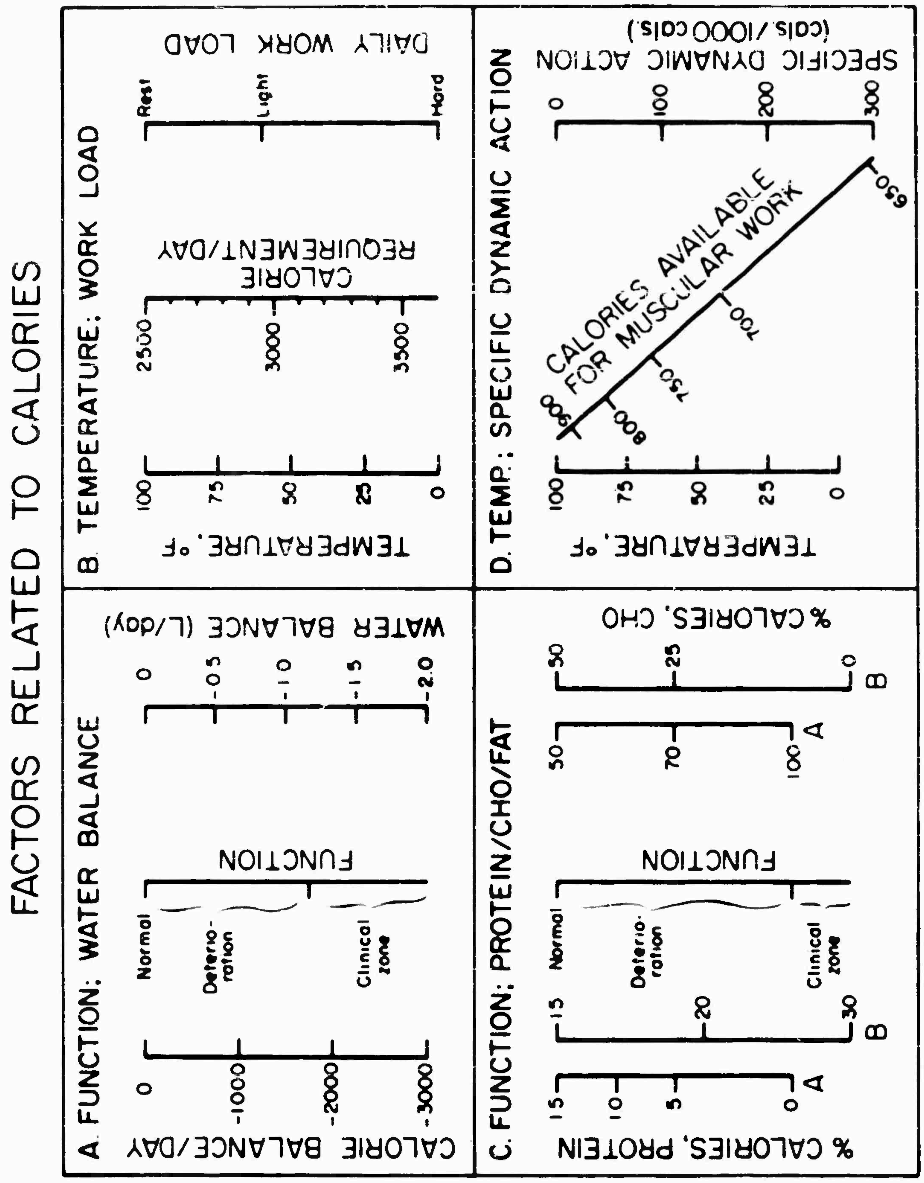
To avoid the appearance of dogmatism in a presentation as brief as this must be, is very difficult; to present full documentation is impossible. Without further apology, I shall present certain generalizations we have made in a five-year study on survival rations. The methods were described this morning. The results described now are to be found in an Air Force technical report (1). We feel that some of the general principles have importance in aspects of human physiology other than the restricted area of survival.

Certain specific conditions were imposed in our studies. The castaway is assumed to be healthy, initially — not injured. His survival kit contains multi-vitamin pills. His environment may be cold, temperate, or hot. His daily physical work may be light (stay by the airplane) or hard (walk twelve miles a day to escape). He will be rescued or abandoned within two weeks. He may have unlimited water, or he may be severely limited in water. His survival ration will be just that: small in caloric content, not planned for indefinite survival.

The general question was, "Is there an all-purpose survival ration?" To answer this question requires establishing four main points. (a) Is a survival ration required at all, or is starvation good enough? The answer is that even small amounts of food are far better than none. (b) Is water supply an important problem? The answer is yes, emphatically. Continued dehydration leads sooner or later to incapacity, and in hot weather to heat stroke. (c) Granted that some food and water are necessary, will the same ration suffice for all environments and all workloads? Or should there be specific survival rations for specific situations? We feel that one and the same survival ration will suffice for all environments and all daily workloads. No low-calorie survival ration can prevent deterioration entirely, but the best can minimize deterioration. (d) What are the physiological, nutritional, and clinical considerations in survival which establish the requirements of the all-purpose survival ration? This last question leads to the presentation of some considerations on temperature, calories, water, osmotic balance, and protein/carbohydrate/fat ratios.

As noted this morning, L. J. Henderson had much influence on some of us. He popularized for physiologists the use of alignment charts (D'Ocagne nomograms) to express quantitative relations among dependent variables. Our generalizations are susceptible of this kind of graphic presentation. Figure 1 deals mainly with calories, Figure 2 with water. The charts must be taken as a description of events, not necessarily as absolute mathematical truths. We have really developed three kinds of charts: (a) qualitative, to include clinical findings; (b) quantitative, to which our data fit empirically; (c) theoretical, to express in a convenient form known physiological relations. I shall describe each of the charts in turn without much discussion.

*This work was supported by Contract USAF 18(600)-80.



Figures, 1A, 1B, 1C, 1D

Function, water balance, calorie balance (Figure 1A). Negative water balance and negative calorie balance are synergistic. If by "clinical zone" we mean circumstances in which subjects became ill enough to require immediate medical attention, there is a combined effect of water-calorie balance which will lead to disability.

Temperature, workload, calorie requirement (Figure 1B). With increasing workloads and decreasing temperatures, the calorie expenditure (and therefore, calorie requirements) increases.

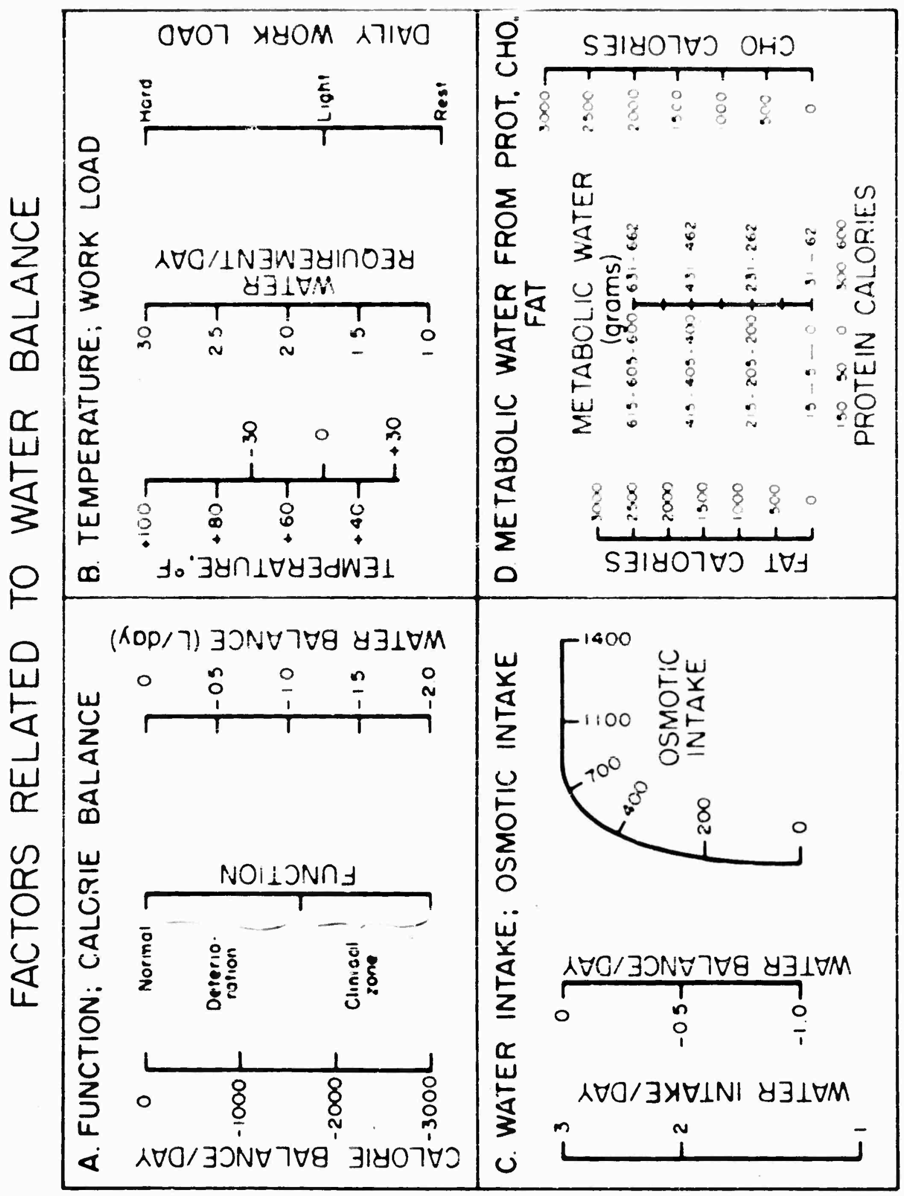
Function, protein/carbohydrate/fat ratios (Figure 1C). This chart summarizes our experience with regimens whose composition deviates widely from what we have come to call the "normal mixture." That is, a regimen whose composition is 15 percent of calories from first-class protein, 52 percent of calories from carbohydrate, and 33 percent of calories from fat. Our lunch today approximated that composition. Every time we deviate from 15/52/33, and the more we deviate, the more marked does deterioration become among the subjects, and the more subjects become clinically ill. This result is not altogether independent of water balance and calorie balance. You can never get truly normal function from a survival ration, but you do get least deterioration from the "normal mixture." The effects of pure carbohydrate are different from those of pemmican; we do not claim that their ill effects are identical. We have observed that they produce more ill effects than does the "normal mixture."

Temperature, specific dynamic action, available calories (Figure 1 D). Calories from specific dynamic action are not available for muscular work; they are for heating the body. At and above the "zone of thermal neutrality," specific dynamic action calories are pure waste so far as muscular work is concerned. In colder environments, specific dynamic action calories are useful to maintain body temperature, and thus "spare" other calories for work.

Function, calorie balance, water balance (Figure 2 A). Incipient heat stroke was observed (total anhidrosis) among subjects in the heat who were dehydrated and in strong negative calorie balance.

Temperature, daily workload, water requirements (Figure 2 B). With increased workload, water loss increases both from the skin and the lungs. With increasing temperatures above freezing, dermal water losses increase. With diminishing temperatures below freezing, pulmonary water losses increase. At hard work in the heat, anhidrosis will appear at intakes less than 3 liters/day. At light work in the heat anhidrosis will appear at intakes of less than 2 liters/day. These observations define water requirements unequivocally.

Water intake, osmotic intake, water balance (Figure 2 C). This chart establishes osmotic balance as a nutritional concept of first importance. When water is limited, a low osmotic intake (a function of the sum of protein and minerals) leads to marked negative water balance; even with unlimited water, water balance remains negative. At high osmotic intakes, above 0.7 osmols/day, water balance is maintained if water is unlimited. With limited water, however, obligatory renal water loss is enhanced by a large osmotic intake (either protein or salt, the kidney does not distinguish), leading to strongly negative balance. There is an optimal osmotic intake, which permits the least negative water balance when water is limited.



Figures 2A, 2B, 2C, 2D

Metabolic water (*Figure 2 D*). This chart is drawn from theory, assuming for survival rations that all foodstuffs in the ration are oxidized. Grams of water are calculated thus: 103 gm from 1000 cal. of protein; 150 gm from 1000 cal. carbohydrate; 119 gm from 1000 cal. fat. The nomogram is a convenience in computing water from oxidation of foodstuffs.

General conclusions. Our conclusion and final recommendation, therefore, is to provide a single all-purpose survival ration. It should come as close as possible to 2000 cal. per day, with percentage of calories 15 from protein, 52 from carbohydrate, and 33 from fat. Two liters of water, at least, are needed for hot weather, one liter for cold. Less than one liter will lead to potentially serious dehydration in all temperatures. Osmotic intake should approximate 0.7 osmols/day. Multi-vitamin tablets are assumed.

We realize that survival rations must represent a three-way compromise among medical, technological, and operational considerations. If you want to compromise the medical aspects, do so with your eyes open as to the possible results. What we have recommended will maintain healthy humans for quite a time in what we regard as almost a normal state. If you drop low in calories or water, or adopt mixtures widely aberrant in protein/carbohydrate/fat ratios, sooner or later you will run into clinical trouble. It may take the form of exhaustion, heat exhaustion, incipient heat stroke, or one of several other kinds of clinical entities. We recommend no compromise, rather than dangerous taking of chances.

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HUMAN PERFORMANCE IN THE COLD

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Our group in Alaska is interested in the factors which may influence health and combat efficiency in the Arctic. We are interested in the effect of cold stress upon performance. But we find it just about as difficult to define "stress" as to measure "performance." It has been said that the Eskimo must be acclimatized to cold stress because he has lived in it all his life. It is true that his forefathers have lived for some 2500 years in Alaska, and yet we find that his body is not really exposed to cold. Measuring his house temperatures in the daytime, you find they are just about 70° F., while they are around 50° F. at night, at which time he is covered by blankets or fur. We find that the Clo value of his two layers of caribou skin, which is about three inches thick, is just about 12 Clos, and that is all he needs for any kind of arctic environment if he is protected from the wind to some extent. Furthermore, we find that even our Air Force clothing, which is far inferior, will take a man to —40° F., protected from the wind, without having to increase his metabolism. We find that conditions such as these exist in the middle of Alaska about 96 percent of the time. Certainly the Eskimo is not exposed to such cold stress as people like to think, with one exception — his face is exposed to cold, and for some reason he is able to tolerate this better than we do.

As far as the methods for measuring human performance under these conditions are concerned, we find the problems equally difficult. Again we have concentrated much of our work on the Eskimo, and we find that obviously the Eskimo gets along much better in a cold environment, just as a New Yorker gets along better in New York than does an Eskimo, because he has accumulated relevant knowledge and experience from childhood. From the age of eight the Eskimo is taken out in a umiak, and he has to row all the time. When he falls asleep his father shakes him and he is forced to row again, without either food or water.

When the temperature is below —40° F. for prolonged periods, we are unable, with our present artificial materials, to provide the airman with adequate protection to enable him to remain in thermal balance while inactive. He has to exercise. And he who can maintain a high level of physical exercise longest has the best chance for survival under these extreme conditions.

To give you an idea of the difference in performance and physical fitness between the average Eskimo, the well trained Army soldier, and the average ariman, we ran the treadmill test and found that the ratio was 3.5 (Eskimo) to 2.5 (Soldier) to 1 (Airman). Thus physical fitness is decisively greater in the Eskimo than in the whites. At the same time the Eskimo has superior clothing which is very flexible. He will take off one layer and is comfortable inside. An airman will take off a whole bundle of clothing to achieve the same comfort. When an airman has to dress in a hurry, it will take him ten minutes, while an Eskimo can do it in ten seconds.

At the same time Eskimo houses are adequate to prevent heat loss. The

Eskimo has adjusted himself to his high meat diet, which is the only diet possible in his situation. It is one which provides the benefits of the specific dynamic action.

So here we have a combination of knowledge, experience, attitude, motivation, physical fitness, endurance, and so on. Concerning the methods for testing, we have been able to make some physiological measurements for some years in men performing certain tasks in the Arctic, and I would like to point out again that this has been useful in showing, as Dr. Lee pointed out, what it costs the man to do certain things, not only in terms of the human body but also as affected by his environment.

For financial reasons, apparently, the Army bought some very heavy skis, four times as heavy as my skis and apparently only one dollar cheaper. In the course of a couple of days the man has spent that much more in calories, so you have lost what was gained by the difference in price. Thus the difference in equipment is just as important to the economy as to the man himself.

Behnke* has pointed out that to measure pulse rate regularly from day to day provides a fairly good index for how you feel and what physical shape you are in. Other than that, we have not been able to find any simple way of measuring predicted performance.

As far as the whole problem of nutritional deprivation is concerned, I shall not take the time now to go into details, but I would like to point out the tremendous individual variations in tolerance and performance under these circumstances. If you would like to see the extreme, you might read a book entitled, *We Die Alone*, written by an Englishman about a Norwegian who in the last war landed in Northern Norway on a military mission. It ended in a catastrophe. Pursued by the Germans, he lived for 41 days in a snow cave almost without food. He swam in ice water on three occasions in one day for a period of time which was far in excess of what you see in the tolerance tables. He skied and he ran and he lived practically without food for I don't know how long. His motivation, of course, was to get over into Sweden.

I had an opportunity also to find out something about the Australian aborigines on my recent trip to the South, and I was amazed to find that these people can walk about for days and weeks without food and perform very well. I have also traveled with the Eskimos and have found they can go a long time without food or water. The same is true about the Lapps in Northern Scandinavia who can roam around in the mountains with only a piece of dried meat for food.

I would like also to mention the fact that the Pribilof seal can lie on the land and fight and mate for about three months, apparently, without water and without food. Maybe we could learn something from the study of this strange creature. This is also true in the case of penguins — they can go for 60 days without food or water.

It seems that by studying these extreme phenomena we might be able to get some idea of what the mechanism is behind it. In general it appears that your actual performance in a given situation may depend greatly on what you did before. In other words, there is a factor of adaptation to be considered. If you give a man pemmican and then give him normal food and then pemmican again, or send him out on a field trial on repeated

*Personal communication.

occasions you will find that somehow he apparently adjusts or adapts to this pemmican ration.

You may be acquainted wi!'. the fact that in some instances people collapse after three days of subsistence on pemmican. I am talking about the kind that contains roughly 50 percent fat and 50 percent meat. The worst day is the third day. If they can somehow survive that third day, they usually pull through. Apparently this is a matter of adaptation.

Our biochemist, Dr. Drury, wondered what the central nervous system had to do with this. He gave one group pemmican alone plus a number of capsules with pemmican also. Another group received pemmican with the same number of capsules of carbohydrate in the amount of 40 grams per day. They did not know what they were getting. One group received nothing but pemmican, and the other group pemmican plus carbohydrate. In both cases the caloric level was roughly 1000 calories per man per day. Over a ten-day period they all looked at each other and couldn't detect any difference. At the end of ten days it was impossible, by clinical observation and performance measurements, to see any difference in the two groups. This was rather surprising.

As far as performance on these low-calorie survival rations is concerned, you send a man out on 1000 calories and he comes back and has lost 15 pounds in weight and his score on the Harvard Physical Fitness Test has improved in almost all cases. One wonders whether this is not just a matter of his having less weight to carry while performing the exercise at the end of the experiment. As we see it, this whole problem of performance is rather complex. We find that in terms of behavior and performance we have to consider the whole person, the whole man, and his reaction to the entire environment. We cannot count pulse beats and say we expect a man to have a pulse rate of 120 under a particular tactical situation. Rather, we have to consider the general health of the soldier, for one thing, and his organ functions, his physical fitness, his mental ability, alertness, mental stamina and motivation. After all, his performance will also depend on his officers and their leadership, and so on. Finally, operational performance under actual field conditions also includes human engineering aspects and the soldier's ability to improvise and get along in a difficult situation, as well as his ability to get along with his fellow men. It appears, therefore, that one has to consider all these aspects of this complex problem before it can be analyzed in terms of an index. First of all, we have to develop an index of the stress we are talking about; and, secondly, an index of the tolerance or performance under these stresses.

Under most circumstances a man is overprotected against heat loss, including most real arctic circumstances, and therefore he does not have to elevate metabolism. Consequently there should be no reason to increase his caloric requirement, except of course for that fraction which is due to the weight and bulk of clothing and the fact that snow is more difficult to walk on than is pavement.

We have been wondering a good deal about the climatization to cold. We find, in the first place, that Eskimos and most soldiers are really not exposed to cold but are protected. We find under these circumstances, even when a man is sleeping in a double arctic sleeping bag outside in —25° F. that his metabolism is exactly the same as it would be if he were inside. In fact, he is in thermal balance throughout. Under these circumstances we

find that there is no increase in food intake over the 5 to 10 percent or what you would expect because of the extra weight and bulkiness of the clothing and the difficulty of walking over snow. Furthermore, we find in the case of the Eskimo that his basal metabolism is identical with ours if we allow for the 9 to 10 percent increase due to apprehension and deduct 15 percent for the specific dynamic action of the high protein intake. If we put an Eskimo on a white man's diet his metabolism is the same as ours.

Next we studied the iodine-131 metabolism and found that there is no change in the soldiers exposed to what cold they encounter, nor is there any difference between them and the Eskimo. The Eskimos on the Coast had the same iodine-131 uptake, the same urinary I^{131} elimination, and the blood levels were not elevated 6, 12, 36, and 48 hours after the tracer dose. The saliva secretion was the same as in whites.

We found in the inland Eskimos and the inland Indians they do have quite a different pattern. They have abnormally high uptakes and high eliminations of I^{131}. They have also lower blood levels of I^{131}. They have extremely low iodine intakes. By giving them iodine for three months we observed a distinct change in the iodine metabolism towards a normal pattern. The frequency of enlarged thyroid is over 25 percent in these inland people. But excluding those people who showed definite signs of endemic goiter, all the other Indians and Eskimos showed no deviation from the normal iodine metabolism.

Soldiers exposed to the Arctic winter, engaged in outdoor exercise, living in bivouacs and so on showed no evidence of altered thyroid function as measured by I^{131} uptake, blood levels, and urinary elimination. We believe, on the basis of all this, that we are not really measuring the response to cold when we are studying these protected individuals in Alaska.

WORK PERFORMANCE IN A HOT ENVIRONMENT

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Dr. Rodahl expressed very nicely the difference between living in the Arctic and having a man nude in the cold. I was not going to comment on the cold except to point out, as Dr. Rodahl did, that the limiting factor of work capacity in the Arctic might well be that imposed by heat stress. We have frequently pointed this out in our own reports, and I notice Dr. Rodahl nodded his head, so I shall not go into that any further.

I would like to make a few comments about the relationship between work capacity and heat, and the fact that a knowledge of these interrelationships might lead to successful search for the simple test of performance capacity that Dr. Henschel asked for in opening the conference. Just briefly, for those who are not familiar with the acute effects of heat and the phenomenon of heat acclimatization, I will take one or two minutes to present the basic facts.

When an individual is abruptly exposed to heat, he can work only with great difficulty. Tasks which are ordinarily performed with great ease are frequently difficult or impossible to complete, due to dangerously high body temperatures and cardiovascular inadequacy. If , however, the individual makes daily attempts to perform a given task, a rapid and dramatic improvement occurs. Within several days he can work with minimal discomfort. This improved ability to work is accompanied by several well-defined physiological adaptations. Thus, in a well-conditioned but not heat-acclimatized man the first attempt to walk for 30 minutes at four miles per hour in an ambient temperature of 120° F. will result in a high pulse rate and high skin and rectal temperatures. In addition, he will subjectively experience great discomfort, accompanied by dizziness, nausea, and possibly syncope. In other words, he behaves as though he had suddenly lost his physical conditioning. Within four to seven days of daily walks the discomfort would be greatly reduced; pulse rate, skin and rectal temperatures, and sweat concentrations of Na and Cl would be lower than on the first day; sweat rate would be higher. These adaptations are the so-called "indices" of heat acclimatization and are summarized in table 1 with illustrative data from studies performed at our laboratory. Other changes that have been reported are increased cardiovascular stability with changing posture, increased blood volume, and decreased metabolic cost for a standard task (i.e., increased efficiency).

Since all the adaptations — both subjective and physiologic — appear to follow the same time course, with maximal improvement during the first week, the acclimatization process seems to constitute a single physiological response. As such, it has been shown to have the following characteristics: (a) it occurs rapidly (4 to 7 days); (b) it can be induced by short exposures (3 to 4 hours daily) if exercise is performed during the exposure; (c) ex-

posure to heat with no exercise confers little acclimatization; (d) it is enhanced by previous good physical condition; (e) it is retarded by low salt and water intakes; (f) it is not enhanced by high salt intake (i.e., over 15 gm NaCl daily); (g) it is retained during subsequent periods of no heat stress (up to 4 weeks), and can be maintained for months with only occasional exposures; (h) acclimatization to a given heat-plus-work load confers complete acclimatization to lesser, and partial acclimatization to higher loads.

TABLE 1.

INDICES OF ACCLIMATIZATION TO HEAT: PHYSIOLOGICAL RESPONSES TO A DAILY 30 MINUTE WALK AT 4 mph (Ambient Temperature = 120° F.)

	First Walk in the Heat	Sixth Walk in the Heat	Response Characteristic of Acclimatization
Pulse Rate	167 per min.	124 per min.	Decrease
Rectal Temp.	102.5° F.	100.3° F.	Decrease
Average Skin Temp.	98.4° F.	96.3° F.	Decrease
Sweat Sodium	134 mEq/L	70 mEq/L	Decrease
Sweat Chloride	128 mEq/L	67 mEq/L	Decrease
Sweat Rate	1085 gm/1 hr	1200 gm/hr	Increase
Subjective Symptoms	Great discomfort, nausea, dizziness	No discomfort	Disappearance

From the foregoing it appears that heat acclimatization and physical conditioning are related phenomena. It also seems that the cardiovascular system is a common denominator in both these responses. Indeed, there is evidence that acclimatization to heat is primarily acclimatization to increased cardiovascular requirements with improved temperature regulation as a "secondary" response.

It has been generally thought that the improved cardiovascular function in heat acclimatization is brought about by an increase in circulating blood volume. However, it can be shown that acclimatization to heat can be maintained without an accompanying increase in blood volume. Similarly, some workers have maintained that improved physical condition is associated with increased blood volume. However, again, recent evidence indicates that this is not a necessary accompaniment of improved performance capacity. We are currently working on the hypothesis that both heat acclimatization and improved physical condition may be associated with increased venomotor tone which, by reducing the volume of the vascular bed, permits improved cardiovascular function without the requirement for an increase in blood volume.

I would like to suggest that evaluation of work performance in a hot

environment as compared with that in a comfortable temperature, may provide us with a "non-destructive" test which will enable us to predict performance capacity. I would like to suggest, also, that an important measurement in validating any such test would involve assessment of venomotor tone. We hope to pursue these lines of approach.

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PERFORMANCE CAPACITY IN THE HEAT

Some Additional Observations

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In his opening remarks Dr. Spector raised the question of reserves and how performance is affected when reserves are low. In the case of a man walking on a treadmill the pace is fixed and the choice is restricted to stopping or continuing. Although the decision to stop is based partly on motivation and partly on the physiological state, our concern is with the latter. What we would like to establish is the physiological basis for the decision to stop under a range of experimental conditions in which the motivation to continue is assumed to be constant, or at least is not intentionally altered by the experimenter. I shall summarize the results of some tests referred to yesterday that have been reported in greater detail elsewhere (6, 7, 8, 9).

The data were derived from 66 measurements on three pairs of men. Each pair was trained to walk on the treadmill in the heat for two weeks, and then spent four weeks on the tests. The conditions varied from pair to pair, but for the whole series ranged as follows:

Metabolic rate; from 160 to 298 Cal/m^2/hr

Room temperature; from 22 to 41° C

Room humidity; from 4 to 26 mm Hg water vapor pressure

Conductance of insensible heat of clothing assemblies and air layer; from 1 to 7 Cal/M^2/hr/mm Hg of water vapor pressure gradient.

Each man walked once a day until he felt he could not continue. The duration of the walk was called the voluntary tolerance (Tm in minutes or Th in hours). During the walk frequent measurements were made of skin and rectal temperatures, and heart rate. The nude weight loss was recorded as a measure of sweat production.

It was assumed that the physiological index most nearly constant over the range of tolerance times would be the one most closely related to the decision to stop walking. In order to examine the data from this standpoint, the indices, listed in Table 1 were plotted against Tm and a best fitting straight line derived according to the general formula

$$\text{Index} = a \pm b\,\text{Tm}$$

where *a* is the intercept and *b* the slope. The mean value of each index, the standard deviation of each observation from the line, and the slope for each index are given in Table 1 with a yes or no for significance of the slope within 19/20 confidence limits.

Significant slopes were obtained in the case of sweat production, final heart rate, and final skin and rectal temperatures. The rise of mean body

TABLE 2.

DATA FOR MEN AT REST IN THE HEAT

Index	Mean	S.D.* of each Obs.	Slope, Units of Variable/min.	Slope Sign.** Diff. from 0
Final rectal temp., °C.	38.4	0.4	+0.011	yes
Final skin temp., °C.	40.5	0.7	—0.043	yes
Final body temp., °C.	39.1	0.4	—0.008	yes
Rise in body temp., °C.	2.7	0.4	—0.005	no
Final heart rate	134	9.4	—0.447	yes
Nude weight loss, kg	0.89	0.24	+0.003	no

Data of Blockley and co-workers; average Tm = 38.8 .64 observation on 12 men.

* From line of best fit

** At the 5 percent level of confidence

temperature and of rectal temperature remained as the most promising indices.

In order to extend the range of the conditions, the data of Blockley and his co-workers (2, 4, 5, 7) on 12 resting men were treated in a similar fashion in Table 2. A significant slope was obtained in the case of final rectal temperature; this left rise in mean body temperature as the favored index.

It is concluded, then, that the decision to stop is made when the mean body temperature has risen by a critical amount. Since this is the basic datum in the caluclation of heat storage, the results establish that the heat load (Sa) is constant at the end of the tolerance time. The slope of Sa plotted against tolerance time was not significantly different from zero so that equation (1) reduces to

$$Sa = \text{a constant} = S \times Th$$

where

S = rate of heat storage in $Cal/m^2/hr$

Th = tolerance time in hours

S is defined independently by a modification of the heat balance equation

$$S = M - Ct(ts\text{-}te) - Cp(ps\text{-}pe)$$

where

M = Heat production in $Cal/m^2/hr$

Ct = Conductance of sensible heat by clothing and air layers in $Cal/m^2/hr/^{\circ}C$ of temperature gradient

te = environmental temperature, in $^{\circ}C$

ts = skin temperature averaged over both body area and time in $^{\circ}C$

Cp = Conductance of insensible heat by clothing and air layers, in $Cal/m^2/hr/mm$ Hg of water vapor pressure gradient across the suit

pe = water vapor pressure of the environment in mm Hg

ps = water vapor pressure of the skin in mm Hg.

Hence we are in a position to relate the duration of performance of work of a given intensity (M) to the conditions of heat (te), humidity (pe) and clothing (Ct and Cp). A detailed treatment for the practical application of this relationship has been worked out by Blockley, McCuthan, and Taylor (3).

The choice of a physiological strain index depends somewhat on the conditions of performance. In a task to be carried out for a period of four or eight hours, the work output must be adjusted to the temperature, humidity, and clothing conditions so that heat loads do not accumulate or can be gotten rid of during normal rest periods. Here sweat production may be a useful index (1) and body water available for sweat formation becomes

TABLE 1.

DATA FOR MEN WALKING IN THE HEAT

Index	Mean	S.D.* of each Obs.	Slope, Units of Variable/min. of Tm	Slope Sign.** Diff. from 0
Final rectal temp., °C.	38.9	0.3	—0.0008	no
Final skin temp., °C.	37.0	0.6	—0.0150	yes
Final mean body temp., °C.	38.3	0.4	—0.0050	yes
Rise in mean body temp., °C.	1.6	0.4	—0.0017	no
Final heart rate	170	9.8	—0.194	yes
Nude weight loss, kg	2.05	0.30	+0.014	yes

Average Tm = 74.5 .66 observation on 6 men

* From line of best fit

** At the 5 percent level of confidence

the critical item of reserve. The present treatment will be most applicable in more acute exposures to heat when thermal equilibrium cannot be maintained. Here the specific heat of the body is the critical item of reserve.

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SOME FACTORS AFFECTING FOOD REQUIREMENTS IN THE ARCTIC

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Under arctic conditions a person may become extremely uncomfortable. I agree with Dr. Johnson that it is quite possible for a castaway to experience the severity of the environment and to require for that reason an extra amount of food. On the other hand, for a person equipped to live in the Arctic the calorie requirements are not much higher than they would be under more temperate climates, and I agree in this respect with the known views of Dr. Rodahl on this subject. I believe that we have enough evidence to prove this point.

First, we know that the average windchill for the arctic winter is about 1780, which corresponds to a still shade temperature of —40° F., to use Burton's terminology (1). A person wearing four clos, which is equivalent to the insulation of the military arctic suit, and doing moderate exercise, equivalent to walking, would remain comfortably warm at temperatures as low as —60° F. At nighttime the decreased heat production will be compensated by the extra insulation afforded by the sleeping bag and by the protection from the wind provided by the tent. It is for these reasons that shivering is very seldom encountered under the conditions I have just described. The hobbling effect of clothing does increase the calorie requirements by more than approximately 100 calories per day (2). Finally, the cost of walking over arctic tundra does not seem to be greater in the winter than in the summertime, as shown in table 1. For these reasons and because of actual measurements of food intake and energy expenditure which I have summarized recently (3), the calorie requirements are much the same in the Arctic as they are in the Subarctic or Temperate Zone and are equivalent to about 3900 cal/man/day for soldiers engaged in simulated military exercises. Since we are talking of performance capacity, I would conclude that generally no extra food is required to maintain a person operational in the Arctic.

However, there may be a great deal of incapacitation due to an arctic environment. I have in mind the local effect of cold. We know, for instance, that chilling of the extremities will decrease manual dexterity, and frostbite is a cause of great concern in the Arctic. Fortunately, humans are able to acquire an increased resistance to cold by repeated exposures. This is especially true for the extremities (4) although we have been able to obtain some indication that the whole body is also able to get acclimatized (5).

I would like to add that one of the main problems in trying to determine the effect of nutrient deprivation on performance capacity is to decide on the appropriate test to use. For instance, in the case of vitamin C, nutritionists are reluctant to abandon the theory that larger doses of this vitamin are needed by men exposed to cold. The work of Dugal and his group on laboratory animals and our own work on humans exposed to cold and fed a low-calorie diet provided some objective and subjective evidence of a beneficial effect of vitamin C. While no incontrovertible evidence is

available, the possibility remains that we are not measuring the proper responses, that we are not giving the vitamin a fair trial. This, of course, may be true for a diversity of nutrients.

TABLE 1.

Heart rate variations in subjects walking at different speeds over hard snowcovered tundra in winter and hummocky dry terrain in summer.

Speed	Winter (18)*	Summer (8)
2.3	102 ± 12**	98 ± 12
2.85	114 ± 13	110 ± 13
3.40	125 ± 12	124 ± 14

* Number of test subjects

** Standard deviation

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THE EFFECTS OF IONIZING RADIATION UPON THE PHYSICAL PERFORMANCE OF ANIMALS

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The effects of ionizing radiation upon performance and fitness in man are largely unknown. Accidental exposures and the atomic weapons casualties in Japan have provided some information which will be discussed later.

It has been possible to determine the effects of ionizing radiation upon the performance of experimental animals under well-controlled laboratory conditions. I would like to summarize some of the observed changes in performance and comment upon some interpretations which may be based on these studies. The methodology employed in testing has been described in a previous session of this conference.

The effects of whole-body X-irradiation upon the performance of rats in an exhaustive swimming exercise test was studied for several weeks after irradiation (8). Pre-irradiation performance tests were made on male littermate rats daily, five times per week, during two weeks prior to radiation exposure. Animals were then distributed into two groups for each experiment. One group (controls) was sham-irradiated, while the other was irradiated with 250 KVP x-rays on Monday of the third week of testing. Radiation exposure doses of 300 to 1000 roentgens (r) were used. In describing the changes in performance, all swimming times for each animal were calculated as percentages of the individual's average time for the second pre-irradiation week. In this manner each irradiated animal served as its own control, and the extent of relative change in performance among different animals could be compared. In addition, the performances of irradiated groups were compared with those of non-irradiated groups for corresponding swimming trials. The performances of animals surviving radiation exposure and the repeated exhaustive exercise tests are summarized in figure 1. Radiation exposure depressed performance in this test, and the magnitude of depression was related to the size of the x-ray dose. Performance scores were at a minimum during three to five weeks after irradiation. Irradiated animals surviving the period of testing recovered sufficiently by the ninth week after irradiation to attain their pre-irradiation performance levels, although they were not identical in performance with concurrently tested non-irradiated animals.

An interesting relationship is suggested by an analysis of the performance for non-surviving irradiated animals in relation to the post-irradiation survival time (figure 2). It can be observed that animals which had "normal" performance scores died during the first week following irradiation, and that the decrease in performance was related to the lengthening of survival time.

The frequency of the exercise of this type likewise alters the prognosis for survival following radiation exposure (9). When animals were exercised by swimming to exhaustion daily after irradiation, there occurred a greater mortality, with more deaths at lower doses, than with irradiation alone. The calculated median lethal dose of x-rays for non-exercised animals was 28 percent higher than that calculated for exercised irradiated animals.

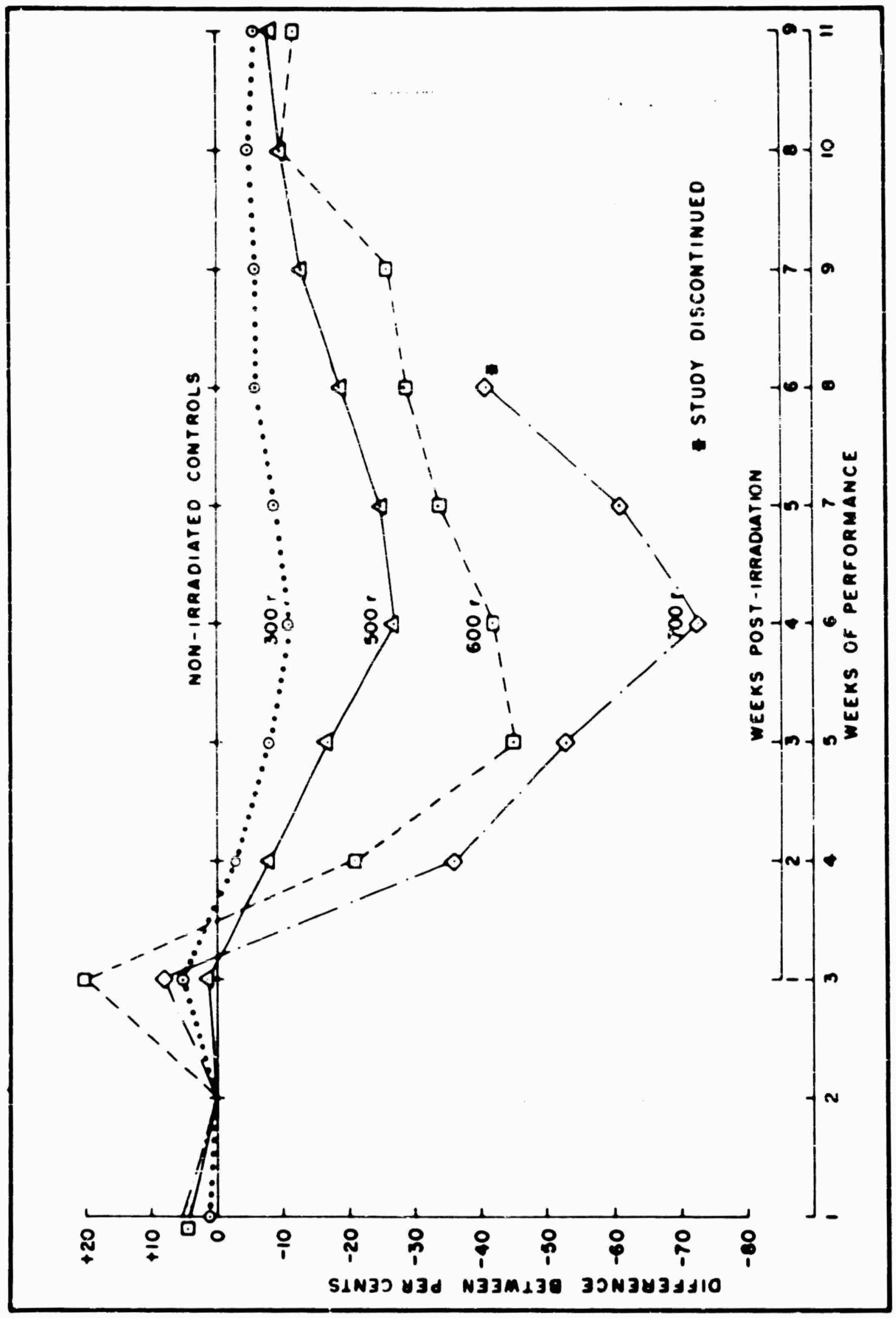

Fig. 1. Difference between exhaustive exercise performance of non-irradiated and surviving groups for each week where performance is expressed in percent of 2nd week's performance time.

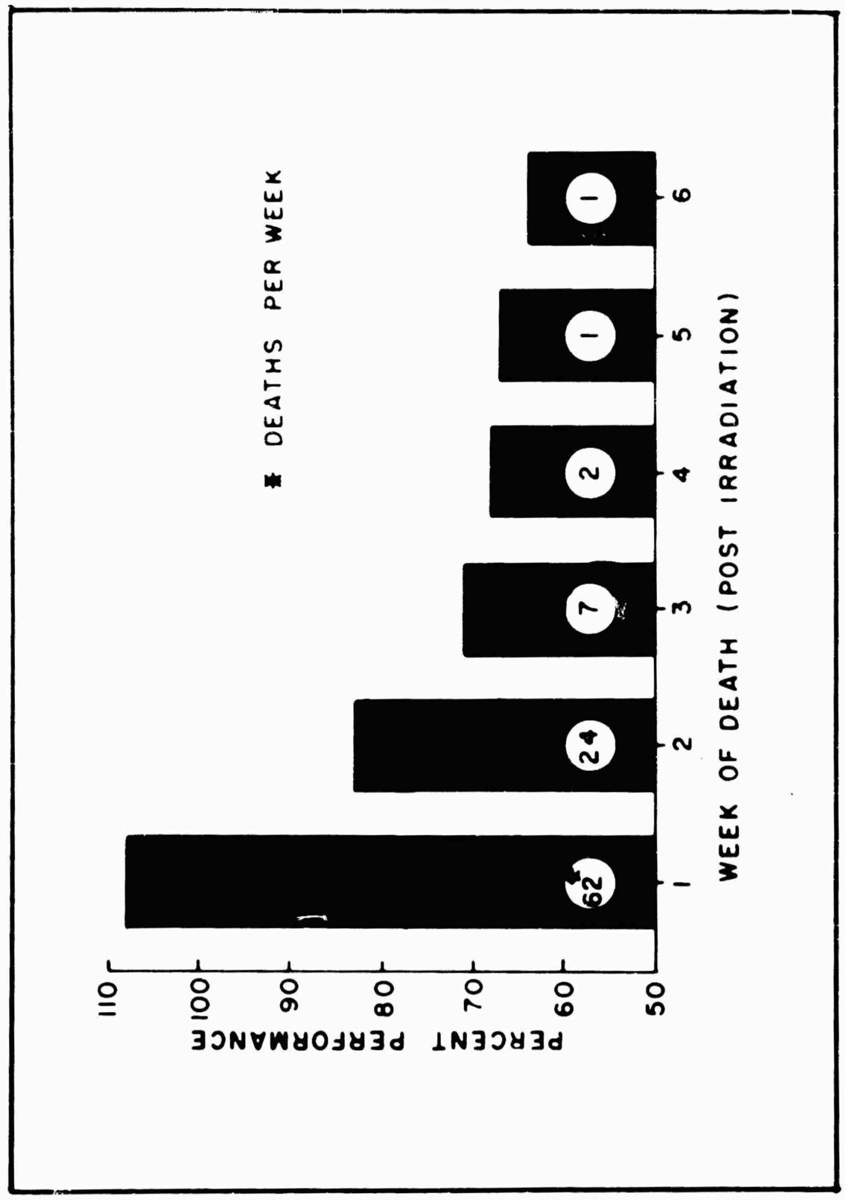

Fig. 2. Post-irradiation survival time as a function of exhaustive exercise of decedent animals during the week of death. Performance values are the means for all animals dying during a given week regardless of radiation dose.

Exercise of lesser intensity than that evoked by swimming, such as walking on a motor-driven treadmill, does not appear to alter post-irradiation survival (11). These findings with less intensive exercise have also been confirmed in our laboratory.

A loss in body weight, lymphoid tissue involution, as well as adrenal hypertrophy are among the consequences of x-irradiation in the rat. These responses are prompt and generally subside during the 30-day post-irradiation period. The imposition of daily exhaustive swimming exercise after irradiation (7) induces a repression of recovery rather than an accentuation of radiation effects. It appears that the increased mortality with repeated exhaustive exercise after irradiation may be explicable in terms of the inability of the irradiated animals to cope with the additional stress of exhaustive exercise.

The effect of whole body acute x-ray exposure upon voluntary physical activity of the adult male rat has been investigated (4). Under controlled conditions of light, temperature, and sound level, the daily volitional activity of each animal was recorded for consecutive periods as long as 11 weeks after irradiation. The results for animals surviving radiation exposure are summarized in figure 3. At all doses studied there was an abrupt depression of activity. This intial decrease in activity was immediately followed by a period of recovery (increasing activity). At 200 and 300 r, recovery was complete within five days after irradiation, and there was no further discernible effect of irradiation upon volitional activity. At doses of 400 r or greater, there was a second decrease in activity, with minimum activity during the third week after irradiation. The time necessary for survivors to complete recovery from this second decrease in activity appeared to be proportional to the x-ray dose. When animals died within the first nine days after irradiation, their activity decreased continuously from the time of irradiation until death. With decedents which survived longer than nine days, the initial decrease in activity was followed by some recovery and then by a second decrease in activity which continued until death.

Decrease of voluntary physical activity is an especially sensitive response to radiation exposure since it is significantly reduced by radiation doses of 50r (x-rays 25 r/min). Modification of the radiation syndrome by partial body irradiation (5) and the use of bone marrow injections (6) attenuates the changes in activity and suggests that voluntary activity deficiencies are correlated with gastrointestinal injury and disturbances in bone marrow function.

The effects of repeated exposure to small radiation doses upon voluntary physical activity have been studied as well. When rats were exposed periodically to small doses of x-rays (50-100-150 r, 25r min) or gamma rays at low intensities (60 r 7.5 r/hr., 75 r at 3.1 r/hr.) activity was depressed for one to two days following most exposures. However, no cumulative effects were apparent over 15 consecutive weeks of measurement (10).

Corollary studies have been made of diffuse physical activity to examine the reliability of generalizations concerning radiation-induced malaise observed in volitional activity studies. The apparatus and technique of measurement were described previously. The diffuse-activity response of the rat following x-irradiation was similar to volitional activity response (figure 4). There were, however, some differences in the degree and duration of change (2). The depression in performance on the day immediately fol-

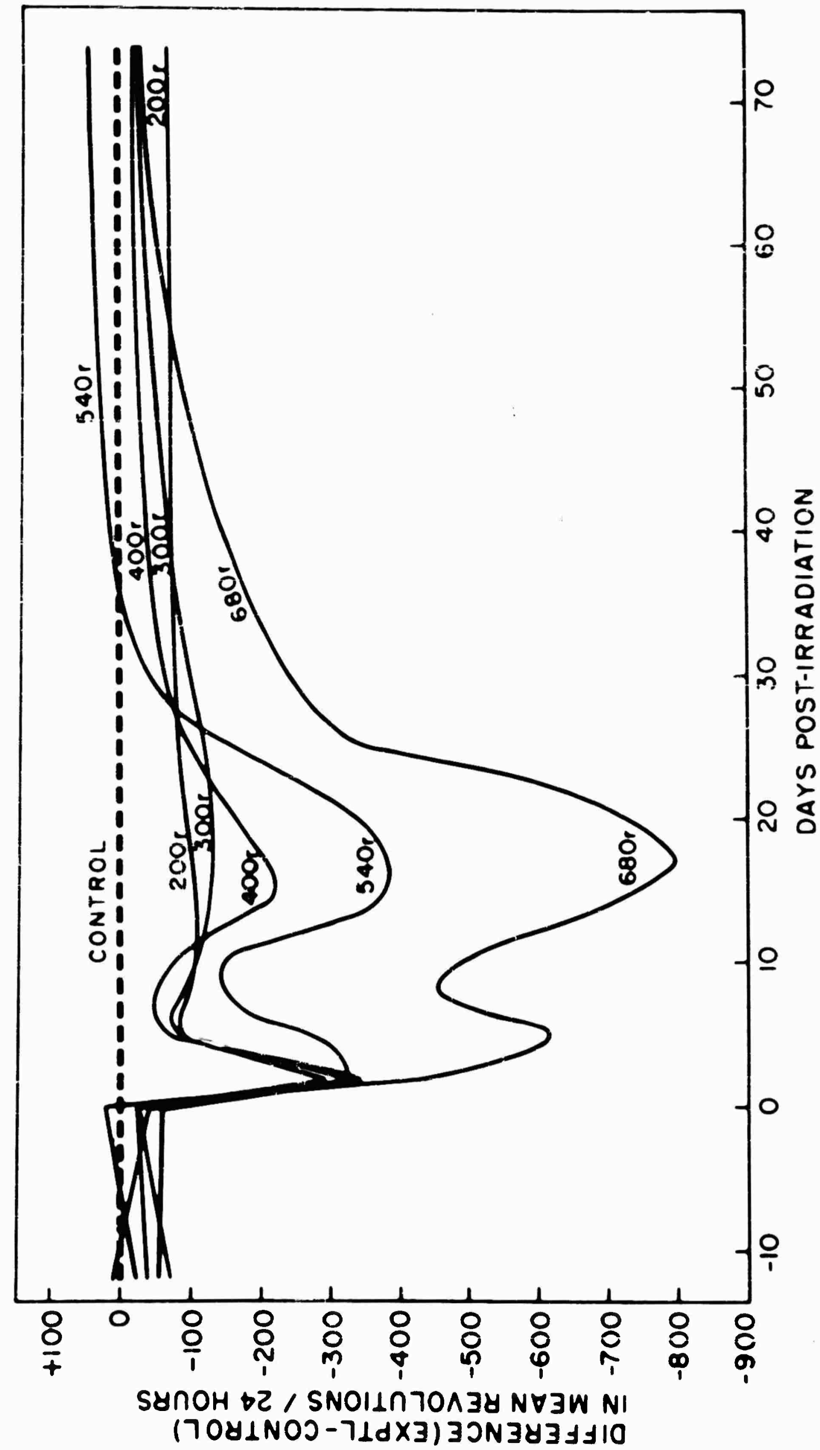

Fig. 3. Effect of single whole body exposures to x-rays upon the daily voluntary physical activity of surviving adult male rats.

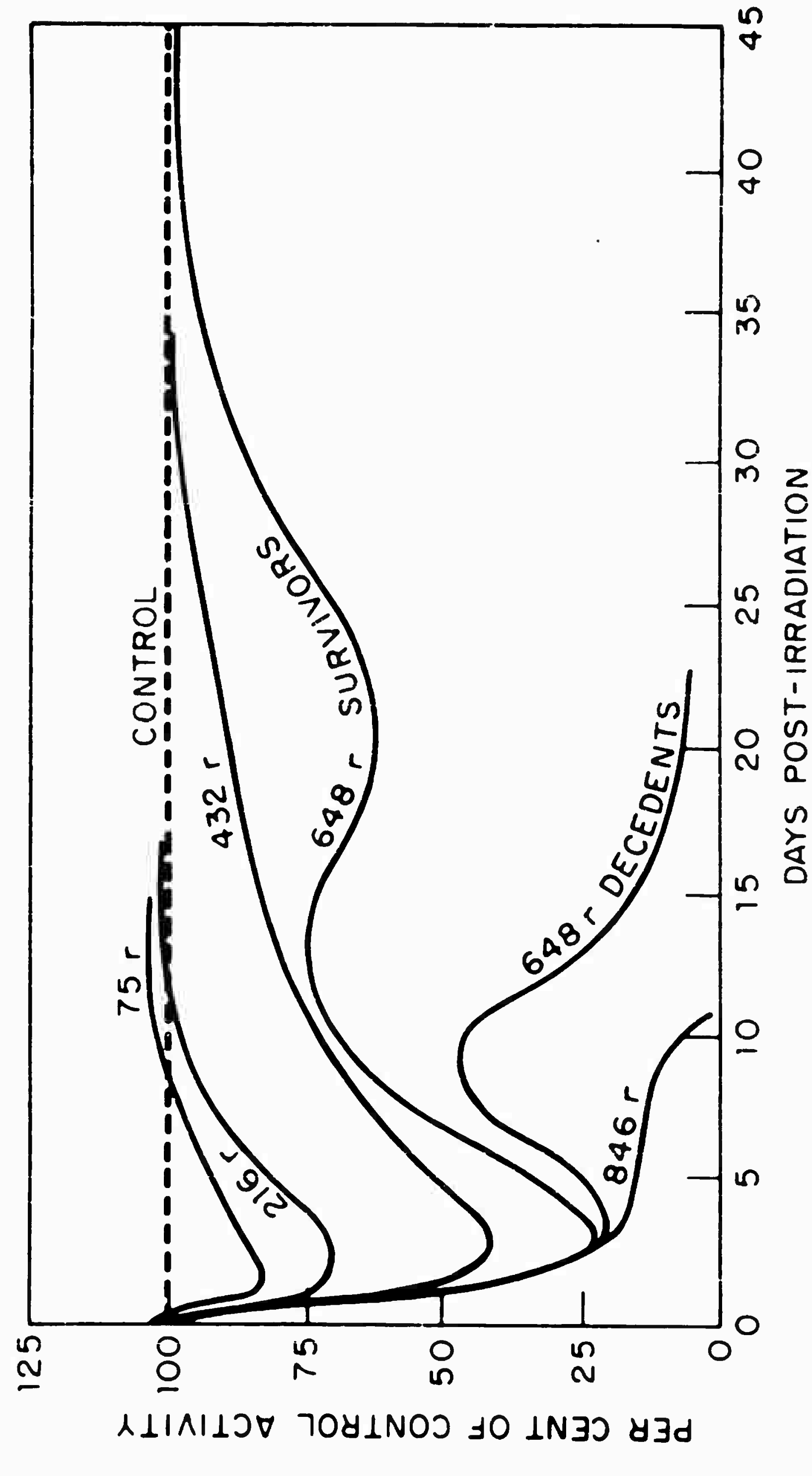

Fig. 4. Effect of single whole-body exposures to x-rays upon the daily diffuse physical activity of surviving and non-surviving adult male rats.

lowing irradiation appeared to be greater in volitional activity for comparable radiation doses. Following exposure to doses in high sublethal, lethal, and supralethal ranges, lowest values occurred on the first day in volitional activity and on the third day in diffuse activity. The second decrease, which began during the second week in volitional activity following sublethal and lethal exposures, was observed in diffuse activity performance only after exposure to a mid-lethal dose. The magnitude and duration of the second decrease in diffuse activity of survivors was not as great as in volitional activity following a comparable dose.

It was also found that neither the magnitude or the time course of the initial decrease in diffuse activity of hamsters and guinea pigs appeared as great as those observed for the rat for comparable radiation exposures. The difference in response appears to be related to the greater radiosensitivity of the gastrointestinal tract in the rat. The rat more closely resembles man in terms of gastrointestinal response.

The dose of radiation need not be large to affect performance in rodents since exposure to a dose as low as 50r of x-rays is capable of disturbing the activity pattern. Likewise, performance deficiencies are not critically dependent upon the specific type of ionizing radiation since both x-rays and gamma rays are effective. Changes have been observed at various energies and over a wide range of dose rates.

A reduction in physical activity appears to be a general response to radiation exposure since it has been observed in rats, hamsters, and guinea pigs and has been described clinically as a symptom of radiation sickness in patients. It may be recalled from the study of swimming endurance that performance times were normal immediately following irradiation and gradually decreased to a minimum performance during the third and fourth weeks. However, the performance of voluntary and diffuse physical activity was depressed sharply during the first week. Since rats are capable of performing normally in an exhaustive exercise test immediately following irradiation, it can be presumed that the initial depression in activity performance is related to a decreased motivation for activity rather than a lowered ability to perform.

There appears to be a remarkable degree of similarity between the biphasic time course of changes in volitional activity performance in rodents and some of the phenomena reported to occur in man following whole body exposure to ionizing radiations. The Japanese casualties of atomic weapons exhibited a radiation syndrome which included, in the initial phase, malaise, nausea, vomiting, and prostration. This was followed by a relatively symptom-free period lasting from several days to three weeks. A second phase of symptoms then occurred, including fever, malaise, hemorrhage, and infection. The severity of each phase was related to lethality of the estimated dose, and deaths occurred during the first phase, with highly lethal exposures, or during the second period of illness with mid- to low-lethal levels of exposure. With sublethal exposure, only the initial period of symptoms was present with little, if any, of the second phase (2). Hempelmann and his colleagues (3) have documented observations on patients accidentally exposed to ionizing radiation and have found that the symptoms generally conformed to the pattern of the acute radiation syndrome observed in the Japanese. It may be recalled that exposure of rodents to sublethal radiation doses produced only an initial depression in activity. As the radiation dose

was increased, the initial depression in activity became greater, and concurrently a second depression appeared during the second to third week after exposure. Rats that died after the first week exhibited some recovery from the initial decline, while rats that died during the first week exhibited a continuous decline to death. It is apparent from these observations that the pattern of activity performance in rodents is very similar to the sequence of events in man following exposure to radiation levels comparable in the extent of lethality evoked.

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PERFORMANCE CAPACITY UNDER CONDITIONS OF CHEMICAL WARFARE

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Since many chemical warfare agents are designed to produce death or incapacitation, it would be reasonable to expect to find a range of dosage in which large or small decrements in performance could be produced at will. Unfortunately, our preoccupation with casualty estimates has left little time for studies on performance. However, advances in instrumentation are expected to contribute to the investigation of the energy requirements of work under field conditions. Within the next year we hope to perfect an instrument for recording the instantaneous flow and hence the volume of respired air. The device will consist of a sensing element mounted on an oro-nasal mask small enough to be worn under the Service gas mask. The object of this device is to measure the volume of air inhaled during a surprise gas attack in the fraction of a minute before the gas mask can be put on.

Aside from this there is one recent study on GB, the anticholinesterase nerve gas, that should be cited (7). After a very low dose by inhalation, with the eyes covered, it has been found that the visual threshold in the dark-adapted eye was increased significantly, even when an artificial pupil was used to screen out effects due to meiosis. Although this is a highly specialized function, it would have a bearing on a variety of operations conducted in dim light.

The defensive aspect of chemical warfare has given rise to more studies on performance than the offensive aspect. Earlier this afternoon I described in general terms the relationship between heat storage and work performance. To this could be added the consideration of the insulation factors of clothing assemblies used to protect against chemical warfare agents.

The specific effect of one component of the assembly, the protective gloves, on manual dexterity has also been studied (6). Several laboratory tasks commonly used by psychologists were employed together with one military task. When the hand was gloved, significant correlations were obtained between all of the laboratory dexterity tasks, but no laboratory task correlated significantly with the military task. This finding appears to be in agreement with the view of K. U. Smith, expressed this morning, that the intercorrelations between different types of neuromotor performance are generally very low.

Although information regarding a variety of tests on individuals wearing protective equipment has been summarized recently (1), when a question arose about a complex task involving 60 men, it was difficult to find a basis for predicting what would happen when the men had to perform the task while wearing protective clothing. The task was the assembly by Engineer Corps troops of a sectional Bailey bridge 60 feet long. It was only by having

the bridge built six times, three times without and three times with protective clothing, including gloves, mask, and hood, that we were able to get some idea of what might happen. The protective gear increased the time required to build the bridge by a substantial amount. The decrement in performance may be attributed to such things as interference with verbal communications and manual dexterity rather than to any effect on the capacity for muscular work. Hard muscular work was required to lift and carry the side frames of the bridge and to advance the bridge on rollers after the addition of each section, but extreme exertion was required for only short times. Intervening operations gave ample time for recovery (9).

The gas mask provides an interesting illustration of the difficulty of assessing the effects of external stress on performance. In running for distances of a half mile (5) or a mile (4), over the ground, the time required to cover the distance was increased by about one-tenth by wearing the mask. On the other hand, in work of about the same intensity or somewhat less, in which the intensity was fixed, as on a treadmill (8) or bicycle ergometer (2, 3), there was no demonstrable effect of the gas mask on endurance time, in trained subjects. These observations raise the question of whether there may not be a difference in the effect of a stress on performance, depending on whether the subject has control of his *rate* of work output.

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ALDOSTERONE EXCRETION IN ANXIETY STATES

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Sodium retention and urine concentration were noted in the study of combat stress in Korea (6). In this same study when ACTH was administered to infantrymen after the stress of five days of defensive action, no measurable increases in urinary 17- hydroxycorticosteroid (17-OHCS) and 17-ketosteroid (17-KS) excretion were observed; however, there was a marked sodium retention. Prior to ACTH administration the samples were also low in 17-OHCS and 17-KS values. The inference was drawn that although the adrenal cortex was non-responsive to ACTH with regard to 17-OHCS and 17-KS excretion, *the gland did secrete some hormone having sodium-retaining activity*. Corticosterone and aldosterone were two steroids considered as possible candidates since both are involved in electrolyte metabolism. Several psychiatric casualties among the infantrymen were also treated with ACTH. These subjects showed a greater than normal response in 17-KS, no response in 17-OHCS, with marked sodium retention. Recently our laboratories (10)and Venning and her associates (19) have independently observed that in certain anxiety states there is an increased excretion of the powerful sodium-retaining steroid, aldosterone.

This presentation will be concerned with aldosterone excretion in various anxiety states. In a few cases data on the excretion of epinephrine (E), norepinephrine (NE), 17-OHCS and 17-KS in addition to aldosterone are presented.

Method. Several extraction procedures for urinary aldosterone were used. In the initial method (I) 24-hour urine sample was continuously extracted for 24 hours with methylene dichloride at pH 1.0 and subsequently chromatogrammed in a propylene glycol-toluene system with elution of the cortisol zone (3). This method was modified (II) to include a second 24-hour period of continuous extraction. Further improvement (III) consisted of a continuous rotary extraction for 24 hours at room temperature at pH 1.0 with methylene dichloride, and subsequent hand extraction with a fresh portion of solvent. Silica gel column chromatography described by Neher and Wettstein (11) was then performed, followed by the ethylene glycol-toluene paper chromatographic separation described by Nowaczynski (12). The extraction and separation of aldosterone by Method III is superior to the other two methods or to the additional use of the Bush System (4) in Methods I and II. The extract prepared for bioassay is cleaner in appearance. All samples were bioassayed for sodium-retaining properties in adrenalectomized rats according to the method described by Cook and Elmadjian (5).

17-OHCS was determined after B-glucuronidase hydrolysis according to the method of Silber and Porter (18) and 17-KS were determined by the method described by Pincus (13).

E and NE were extracted by the adsorption method of von Euler and Hellner (20) and bioassayed according to method of Gaddum and Lembeck (9) as described in our previous publications (7).

Results. Data on aldosterone excretion obtained with Method I are presented in Table 1 (10). The normal mean value was 2.4 $\mu g/24$ hrs. The chronic schizophrenics showed an average excretion of 1.1 μg/day. Ten urine samples of the group had no measurable amounts of aldosterone. The acute schizophrenics and the non-psychotic subjects with anxiety symptoms showed elevated aldosterone values.

The question was raised as to whether chronic schizophrenics did in fact

show no aldosterone excretion. One possible explanation was that none would be detected with the particular extraction procedure employed. A second 24-hour continuous extraction or a hand extraction was instituted in addition to the first 24-hour continuous extraction. We observed that an additional amount of aldosterone was extractable by this procedure. The data obtained with Methods II and III are presented in Table 2. The mean value for normal subjects was now raised to 4.1 μg/24 hrs. Schizophrenic subjects showed a wide range of values with a mean of 4.4 μg/24 hrs. Neither acute nor chronic schizophrenia influenced the excretion rate of aldosterone, and, as far as could be ascertained, the rate of excretion was influenced only by the emotional state of the subject at the time of sampling.

In Table 3 are presented data on 17-KS, 17-OHCS, E and NE in addition to aldosterone excretion in 24-hour urine samples on the group of subjects in anxiety states. The individuals are those included under Table 1. The description of each subject is given in Table III. All subjects showed high daily levels of aldosterone excretion. The other criteria of adrenal gland activity were unrelated to aldosterone excretion.

In Table 4 are the data obtained from six additional subjects with psychoneurosis. We note that three of these subjects with anxiety neurosis showed an elevated aldosterone excretion, two had normal values, and one showed no measurable amount of aldosterone. Brief clinical descriptions of representative cases are given below.

Case History: Sw.

This patient was first admitted to the New England Medical Center in the summer of 1946 when she was 19 years of age. She was referred to the hospital on this occasion for endocrine evaluation, because of amenorrhea. After a thorough work-up, a diagnosis of sexual undevelopment was made, and she was placed on medication with thyroid and Stilbesterol. The therapy was effectual in producing normal menstrual periods. However, after a few months, she discontinued the medication because of the expense.

Sw. was again admitted to the hospital on December 10, 1956. Her chief symptoms at this time were varying manifestations of anxiety. She would lie awake at night plagued with fears of having a number of serious illnesses. In her waking hours she was preoccupied to a great extent with imaginative impending catastrophes. Periodically she experienced attacks of difficulty in breathing, palpitation, and fearfulness which lasted from 10 to 15 minutes.

Physical examination revealed the patient to be a rather small woman 30 years of age. There were no unusual skin lesions. The blood pressure in the right arm, obtained in a reclining position, was 140/90; the pulse was 100 and regular. The cardiac rhythm was regular. There were no audible murmurs. There was no cardiac enlargement.

Mental status examination revealed Sw. to be extremely tense and apprehensive. She periodically wept. She expressed fears of dying or never leaving the hospital alive and of having a number of serious diseases. There was no unusual thought content elicited. Her associations were direct, logical, and to the point. Her affective response parallelled her thought content.

While in the hospital a 24-hour urine collection was made for aldosterone. During the period in which this urine specimen was collected, Sw. was exceedingly tense, apprehensive, and experienced overt attacks of anxiety characterized by difficulty in breathing, palpitation, and fear.

Diagnosis: 1. Anxiety neurosis
2. Primary hypogodanism

Case History: Pem.

This patient was admitted to the hospital in July of 1956 with a chief complaint of insomnia, "nervousness," "indigestion" and back pain. Pem stated that he had been troubled by insomnia since boyhood. He expressed the opinion that during the last two or three years the insomnia had been worse. He noted for as long as he could remember he tired rather easily and did not have the stamina of his associates. This fatigue he stated had been worse during the past two or three years.

Over the years he had visited doctors concerning his chief complaint and on one occasion was hospitalized for a thorough evaluation. No organic disease was discovered in these examinations. Recently, since the symptoms appeared more frequently, he decided to "come in for a check-up."

Physical examination revealed Pem. to be a heavy-set, well-developed muscular man 59 years of age. There were no unusual skin lesions and no significant adenopathy. The blood pressure was 130/80 in the left arm in the recumbent position. Cardiac rhythm was regular; there were no murmurs audible; heart sound was somewhat distant, which was ascribed to thickness of the chest wall.

Mental examination revealed Pem. to be somewhat tense and apprehensive. He spoke in clear, relevant associations. He was quite alert mentally. There was no disturbance in intellectual functions. There was no evidence of primary mood disturbances.

A 24-hour urine sample was collected for aldosterone. During the period in which the specimen was collected, Pem. was quite restless and tense. The night was a difficult one for him. He did not sleep. He attempted to lie in bed and read, found himself too restless to do so, got out of bed and took a shower on several occasions.

Diagnosis: Anxiety neurosis

Some notes on the status of other patients during the 24-hour urine collection period revealed the following:

Res.: Though extremely tense to the point of overt tremulousness, a week prior to her urine collection, she was not unduly tense during the period that urine was collected. She described herself as being somewhat "nervous," but not as anxious and tense as she had been on other occasions.

Hol. He described himself as being "pretty much O. K." during the time of the urine collection. He did speak of having a tense forenoon on the day of the collection, but was not unusually uncomfortable.

Anxiety may manifest itself by acute attacks consisting of breathlessness, palpitation, tenseness, fear, chest pressure, and perspiration or by protractive states of unrest, continuing for several weeks or months. Anxiety as a symptom occurs in uncomplicated form in a syndrome termed "neurocirculatory asthenia" or anxiety neurosis. On the other hand, attacks of anxiety or prolonged states of tenseness and unrest may occur in a number of other diseases, i.e., hysteria, delirium, agitated depression, schizophrenia, obsessive-compulsive neurosis and various organic brain symptoms. In view of the multiplicity of factors it is not surprising that the aldosterone excretion is not correlated with specific diagnosis. As was suggested earlier, it appears to be a function of the anxiety state at the time of the urine specimen collection.

Finally, four samples were obtained from local hospitals with the

request for measurement of urinary E and NE because these patients had vasomotor symptoms which in the judgment of the physican required laboratory data for a possible diagnosis of pheochromocytoma. Although samples from all four subjects had normal E and NE content, one had an aldosterone value of 8.0 $\mu g/24$ hrs. and the other three had values over 10.0 $\mu g/24$ hrs.

Discussion. The results at first glance seem at variance with our previous findings, relating variations in E and NE excretion in various emotional states (8) inasmuch as the subjects reported in this study showed emotional displays or vasomotor signs indicating sympathico-adrenal activity, yet the catechol amine excretion was not elevated. Two possible explanations may be offered: (a) There may be in these cases increased rates of metabolism of the catechol amines secreted to biologically inactive derivatives appearing in the urine, or (b) the response to the quantity of catechol amine produced is exaggerated so that normal amounts of E and NE secreted result in a greater than normal physiological response. A review of the data with respect to the latter possibility has been presented by Raab, et al (14). A study of the metabolism of epinephrine and norepinephrine is at present being pursued in our laboratories (16, 17).

The findings related to the steroids excreted in these cases are in need of some explanation. We found several subjects who excreted very low amounts of 17-OHCS, normal amounts of 17-KS, but showed high rates of aldosterone excretion. It is of interest that Albeaux-Fernet and his associates (1) reported that in chronic asthenia they obtained low 17- OHCS excretion with low 17-KS. They further observed that these subjects did not show increased 17-KS and 17-OHCS excretion after ACTH injection. Data were presented indicating *increased excretion of 17-desoxy C21 steroids*. The inference drawn was that corticosterone was the major adrenal cortical steroid secreted in chronic asthenia. The similarity of these results and the inferences drawn to those of the Korean study discussed in the earlier portion of this paper should be noted.

The following hypothesis relating to adrenal steroid biogenesis and metabolism is presented to relate possibly the various findings in adrenal steroid secretion to stress, and especially to explain, in part, the elevation of aldosterone in certain anxiety states. The adrenal cortex in the first stage of stress secretes 17-OHCS which are measurable by the Porter-Silber reaction (18) and some 17-KS which may be estimated by the Zimmerman reaction (13). As the stress continues either the adrenal cortex ceases to show an increment of 17-OHCS with an increase in 17-KS, or the 17-OHCS secreted are more rapidly metabolized to 17-KS (6). As the stress is further sustained, both the execretion of 17-OHCS and 17-KS are low due primarily to inhibition of 17- hydroxylating mechanism in adrenal corticosteroid biogenesis (1). This inhibition of 17-hydroxylation would favor the biogenesis of corticosteroids of the 17-desoxy C21 type. The two principal candidates in this regard would be corticosterone (compound B) and aldosterone. At this stage ACTH injection would not show an increase in 17-KS or 17-OHCS but an increase in steroids of the 17-desoxy C21 compounds which would include corticosterone and/or aldosterone (1, 6).

The significant contributions of Bartter (2) on the factors influencing the secretion of aldosterone, such as electrolyte and water balance, and the findings of Rauschkolb and Farrell (15) showing possible diencephalic regulation of aldosterone secretion certainly make this area of study of great

interest in the understanding of the physiology of stress as it relates to adrenal cortical function.

Summary. Aldosterone excretion has been shown to be elevated in certain anxiety states. The possible relations between adrenal medullary and adrenal cortical functions were discussed and a hypothesis was presented with respect to biogenesis of adrenal cortical steroids in chronic stress situations in man.

TABLE 1.

EXCRETION OF ALDOSTERONE IN 24-HOUR SAMPLES* (10)

	N	μg Aldosterone equivalents/24 hrs.
Normals	8	2.4 (2.0 — 3.3)
Schizophrenics (chronic)	18	1.1 (0.0 — 5.4)
Schizophrenics (acute)	4	5.4 (2.9 — 7.9)
Non-psychotic Anxiety states	10	10.3 (8.0 — 12.2)

* Extracted by Method I. See text under Method.

TABLE 2.

ALDOSTERONE EXCRETION*

	N	μg Aldosterone equivalents/24 hrs.
Normal	9	4.1 (2.4 — 4.8)
Schizophrenics	14	4.4 (1.2 — 10.0)

* Extracted by Methods II and III. See text under Method.

TABLE 3.

NON-PSYCHOTIC SUBJECTS IN ANXIETY STATES

Subject	Description	Aldosterone µg/24 hrs.	17-OHCS mg/24 hrs.	17-KS mg/24 hrs.	NE µg/24 hrs.	E µg/24 hrs.
For	Doctorate Examination	10.0	1.82	10.8	64.8	9.1
Thomp	Compensated Malignant Hypertension — Anxiety State	10.0	8.64	2.88	31.2	2.9
O'G	Chronic Anxiety Neurosis	12.2	12.96	6.48	48.0	....
Cock	Anxiety Neurosis	9.3	15.6	16.10	21.6	1.9
Torn	Essential Hypertension Anxiety State	8.0	9.84	....	13.8	1.7
Lor	Chronic Anxiety Neurosis	> 12.5	1.20	....	14.4	1.7
Ger	Anxiety Neurosis	10.0	3.10	12.6	....	....
Cre	Suspected Pheochromocytoma	8.0	9.36	....	40.8	3.6
Can	Suspected Pheochromocytoma		.96	....	40.0	2.4

TABLE 4*

PSYCHONEUROTIC SUBJECTS

Subject	Description	μg Aldosterone/24 hrs.
Hol	Anxiety Neurosis and Depression	8.0
Pem	Anxiety Neurosis	> 10.0
Sw	Anxiety Neurosis	> 10.0
Res	Hysteria	0
Gi	Anxiety Neurosis	2.4
Cha	Anxiety Neurosis and Depression	4.0

* Aldosterone extracted by Method II and III.

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PSYCHOLOGICAL MEASURES OF PERFORMANCE, WITH SPECIAL REFERENCE TO LOW-ANXIETY AND HIGH-ANXIETY SUBJECTS[1]

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The research to be described here is a part of a program on the application of electronic methods of motion analysis to the assessment of drug action and of the effects of emotion on performance in man.

Turning now to specific tests, I shall proceed to illustrate them and comment in each in turn. Figure 1 is a diagram of a paper-placing task. The individual simply moves the paper from one place to anther — a very simplified task. We find that one of the very important dimensions in motor performance is the complexity of the movements involved.

Figure 2 shows a combination reaction-time board. We can record separately the simple reaction time and the discrimination reaction for hand and foot. In the background you can see a bimanual switch-turning task. We can set this up into a complex task where we have alternating movement patterns.

Figure 3 illustrates a switch-turning task which yields very nice learning curves. It is useful for estimating fatigue effects since you can run a subject through it either on space trials, once through the board, or on mass trials, having him do it ten times in a row.

Figure 4 shows a mental maze — we can vary the number of competing responses, a convenient way to control the complexity of the task.

Figure 5 is an assembly task in which we can vary perceptual complexity.

Figure 6 represents a problem of classification.

In conducting studies on the relation between emotion and motion characteristics, we separate our subjects into the high-anxiety and low-anxiety groups, defined psychometrically. One may think of this as a chronic, long-term emotional stress situation. The high-anxiety group may be considered as people who are walking around with a mild emotional stress within them. The high-anxiety subjects spend more time manipulating and less time traveling on the same task than do the low-anxiety subjects (Figure 7). The number of contacts in this simple assembly task gives us a measure of the number of fumblings and errors in placement. We find that as task complexity goes up, the low-anxiety group is not affected. The high-anxiety group, however, shows a very marked increase in errors or fumbles as a result of increased task complexity.

[1] This preliminary research is a part of a continuing project on application of electronic methods of motion study and biokinetic aspects of emotion and drug action in man. The Psychopharmocology Laboratory, The University of Wisconsin, is under the joint direction of Karl U. Smith and Fred Shedeman. This work was supported in part by the Graduate School Research Committee, the University of Wisconsin. Research funds for motion analysis devices came in part from the NSF.

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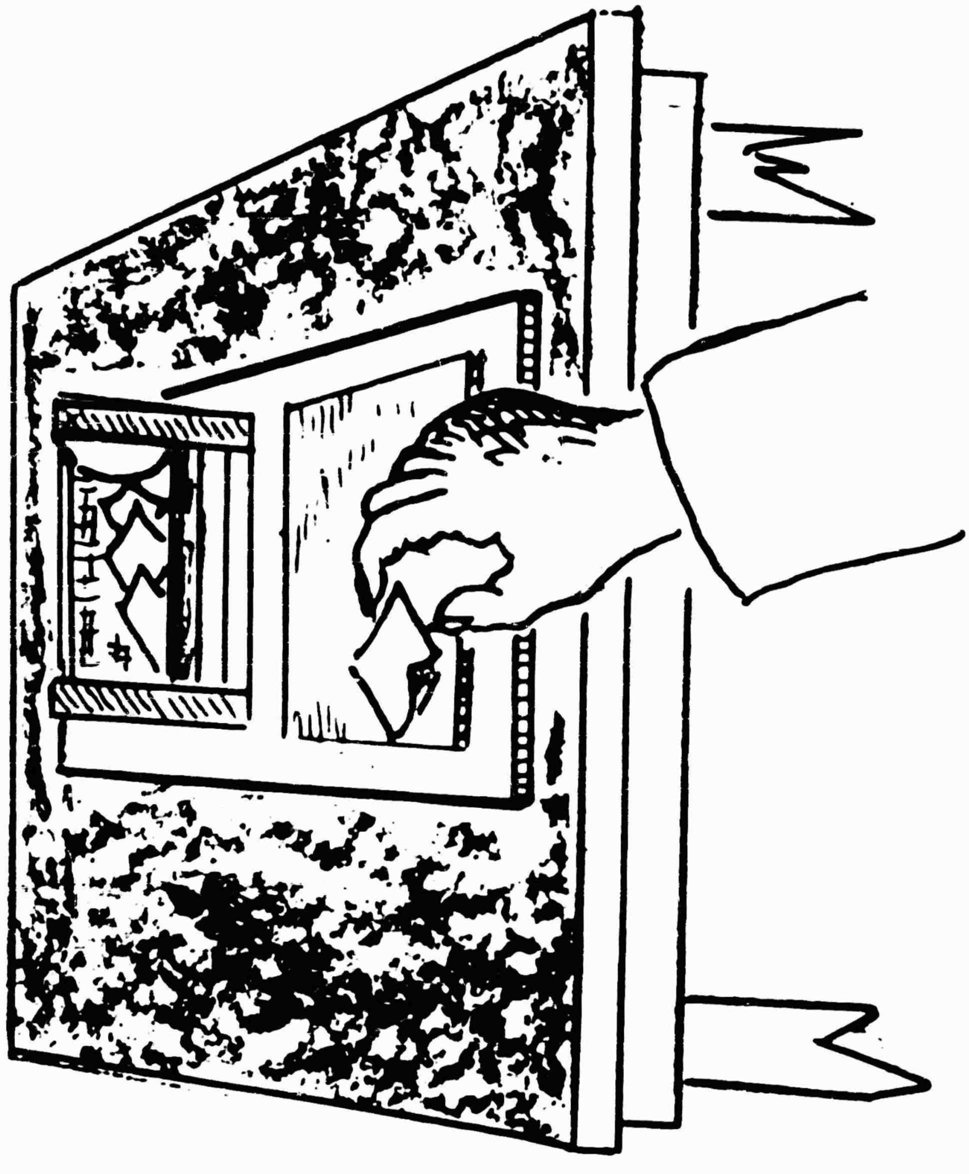

Figure 1. Diagram of Paper-Placing Task, analyzing travel and manipulation components of human motion separately and distinguishing between high and low anxiety subjects.

Figure 2. Combination Board analyzing simple and Discrimination Reaction times with a complex toggle switch turning task located at the rear of picture.

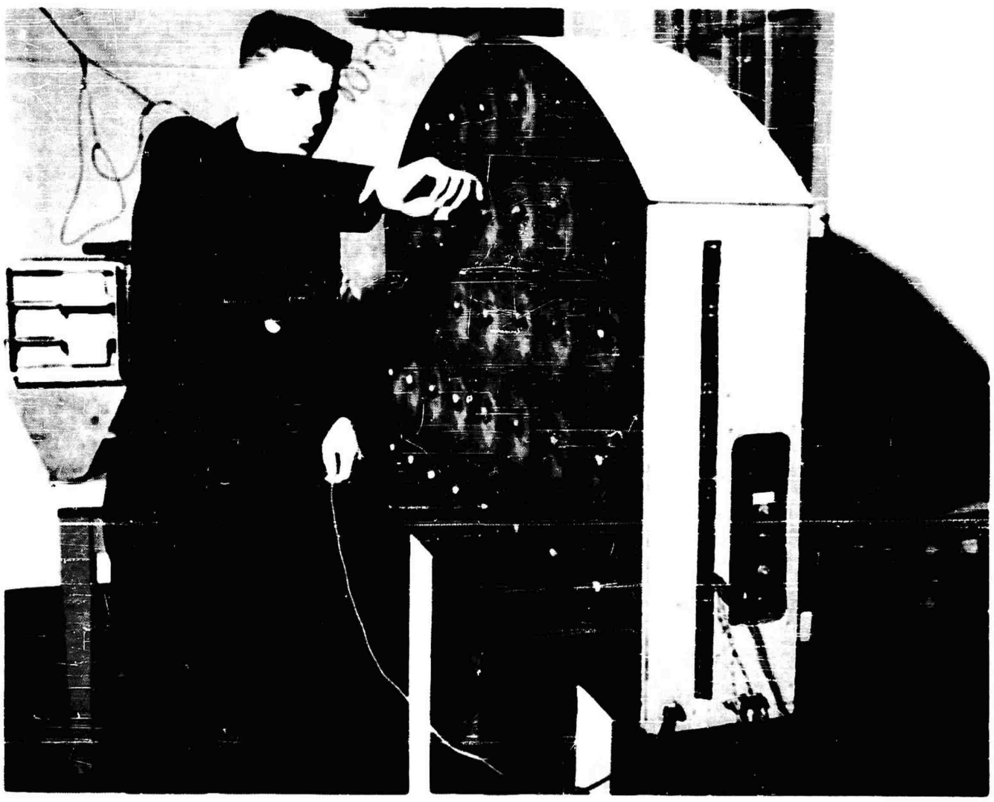

Figure 3. Switch Turning Task analyzing separately Travel and Manipulation components of human motion. Fatigue effects are sensitively recorded by an increase in manipulation (or resting) time and a corresponding decrease in travel time.

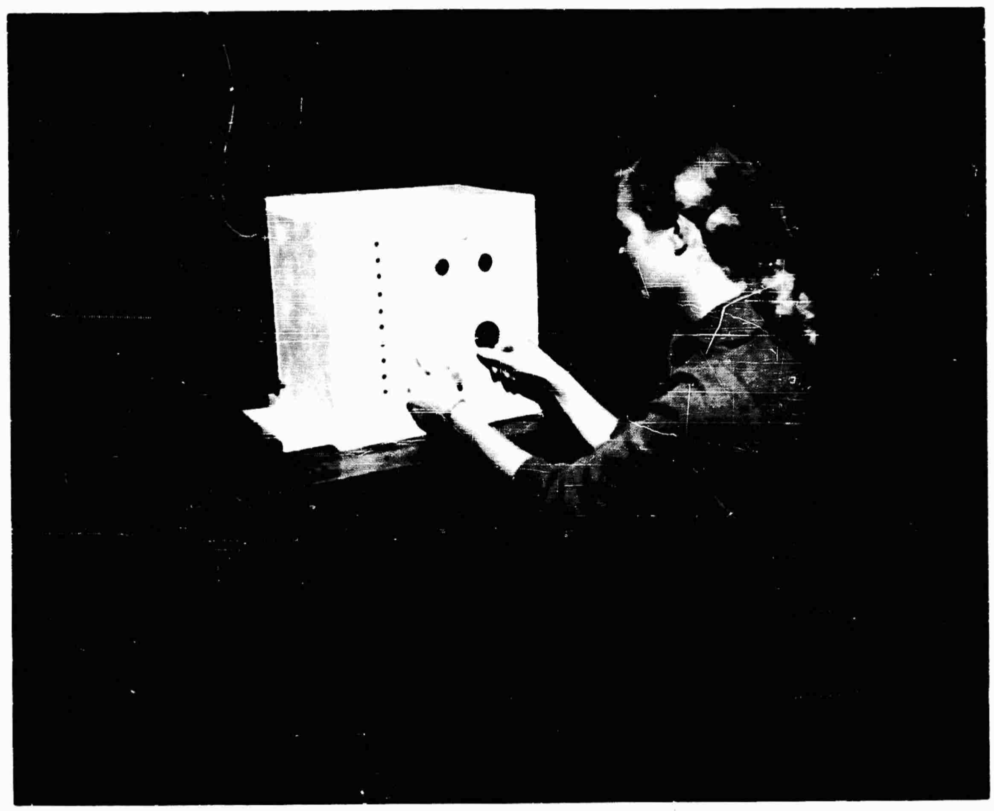

Figure 4. Mental Maze apparatus which automatically records errors and correct responses. The subject is given 10 "choice points" in the mental maze and task complexity is varied by allowing from one to 10 choices at each "choice point."

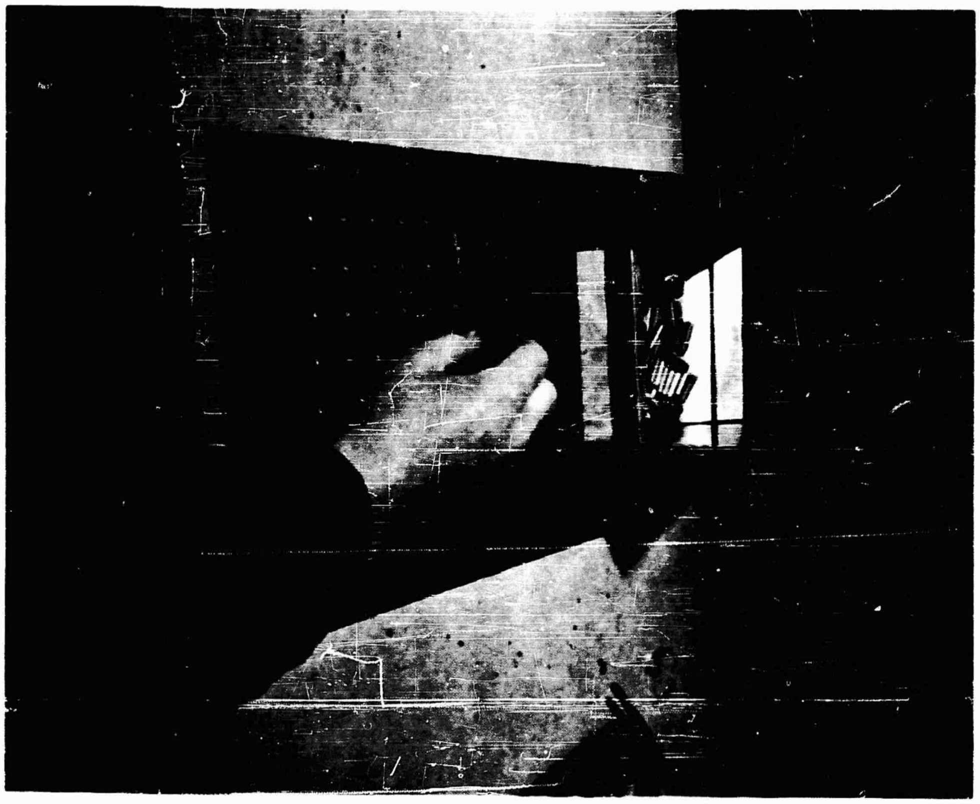

Figure 5. Pin Assembly Task. By requiring the subject to assemble according to a prearranged pattern the assorted brass and steel pins complexity can be varied in a perceptual-motor dimension, with separate recording of manipulation and travel components.

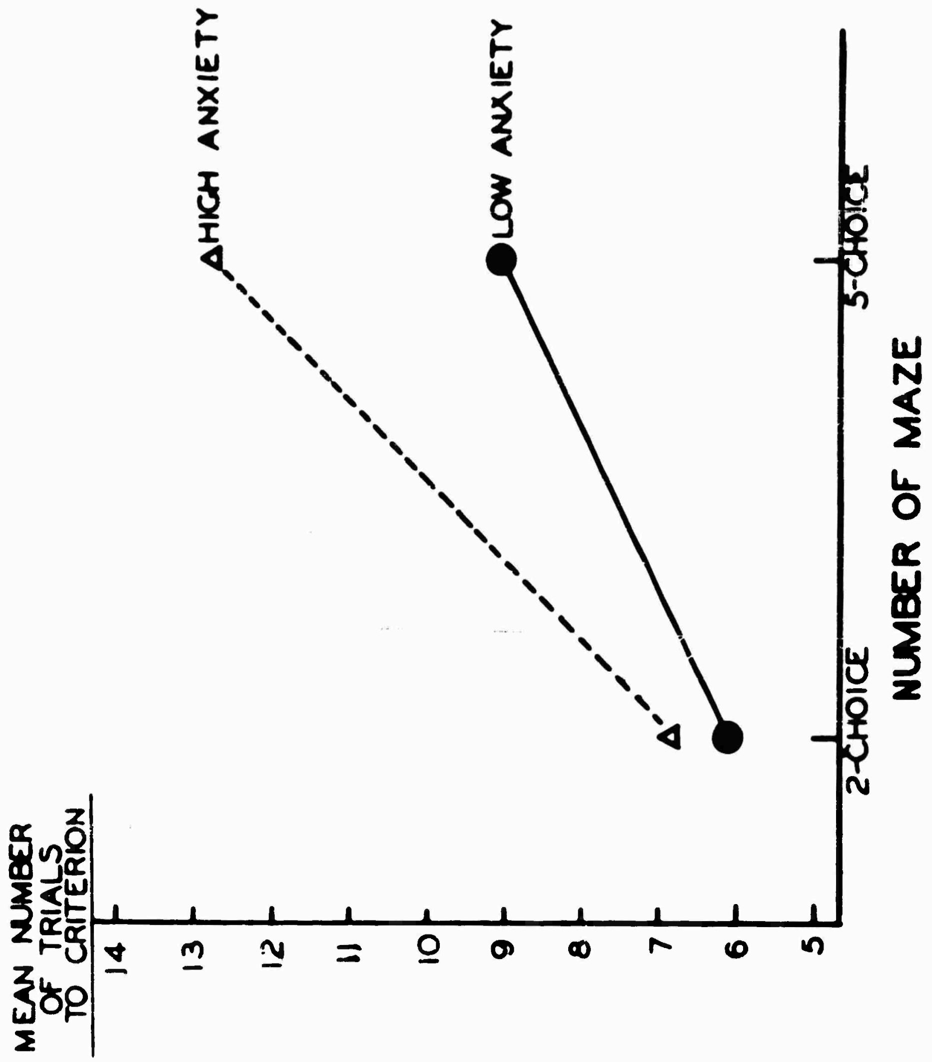

Figure 6. Anxiety Level of Subjects differentially affects performance on simple and more complex mental maze tasks. Only a slight increment in trials to learn a more complex maze is required of low-anxiety subjects, whereas high-anxiety subjects require almost double the trials to learn the more complex maze.

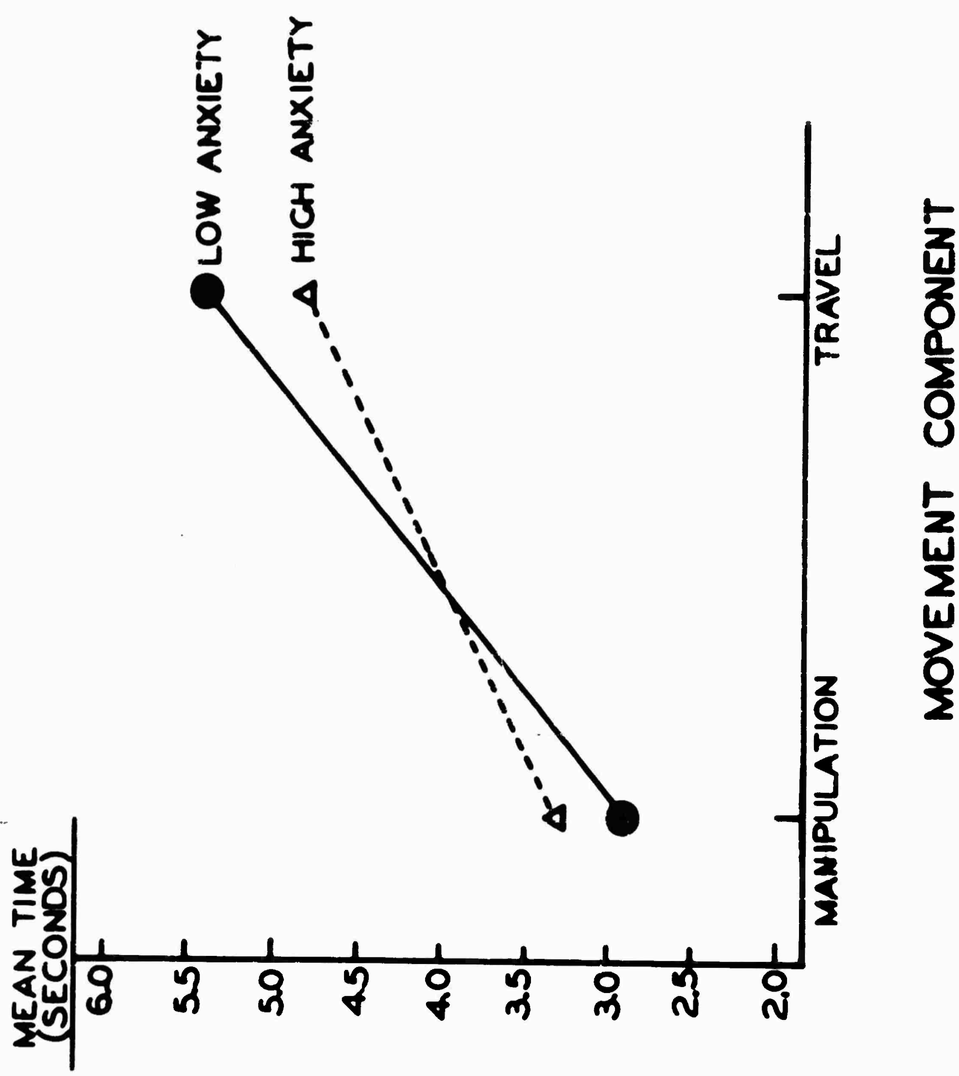

Figure 7. Differential Effects of Anxiety upon travel and manipulation components of human motion. Although high- and low-anxiety subjects show no difference on some tasks in overall performance, the effect of anxiety upon the economy of motor performance is shown by the differential effect upon travel and manipulation times.

Besides the manual tests described here, we have also made studies of the effects of drugs and of emotional state on handwriting and gait movements. Results of these motions are of particular interest inasmuch as the motions involve only limited learning effects.

In addition to these preliminary observations, we also have examined a number of general tests of intellectual performance in relation to emotion and to the effects of drugs. Among a number of such tests, it was observed that a test of addition of 2-digit numbers might be as valuable as any.

V. GENERAL DISCUSSION

Highly Stressful Situations.

GROSSMAN: We know that for almost all physiological functions we can decrease the reserve by a very large amount before any change in function occurs. Then, at some level, we get a precipitous fall. One of the main reasons for the application of highly stressful situations in testing is not to determine whether or not the individual is capable of performing the stressful task, but to determine where he is on this reserve-versus-stress curve. This is the means by which we uncover a deficiency that does not show up in the steady state (or, even less so, at rest).

If we have no caloric deprivation (i.e., if we have 100 percent caloric balance), we have also 100 percent work capacity. We can go quite far down along the scale of caloric deprivation before we find a detectable influence on work capacity.

The level at which we begin to get a decrease in work capacity is viewed by many as being extreme and impractical to measure. It is asserted that such a level has no practical significance because it is unlikely to be encountered in military or civilian situations. But we need to apply extreme stresses in order to determine how much reserve there is. That there is a dichotomy between laboratory testing and the practical situation is readily accepted. We need a critical appraisal of both of them. We need laboratory tests because we do not encounter stress problems under satisfactorily controlled conditions in the practical or field situation. Let us consider blood volume and blood pressure for a moment. We know that one of the important determinants of blood pressure is blood volume, and we know that very significant decreases in blood volume can occur without affecting blood pressure. So, the simple measurement of blood pressure becomes a poor measurement of the reserve of the blood volume. Only the direct measurement of blood volume will tell us how much more blood an individual can lose before he gets into trouble.

For caloric reserve or for other factors, once we have established this relationship in the laboratory, direct measurement of the factor itself would represent the reasonable approach, and much of our attention should be directed toward that aspect of the problem.

One other comment: If men are calorically deprived, receiving some 1500 calories per day for four weeks, and have lost 10 percent of their body weight (which represents close to 20 percent of their caloric stores), they are still able to perform, in terms of our standard testing procedures.

If we ask whether these men are able to perform a 25-mile hike with full equipment, the answer is yes, they can do it. If we ask the man before the hike whether he feels impaired and whether he feels as though he were going to be able to do it, his answer will be no. So this question of "optimal" work conditions has to be regarded in the light of what practical situations we are going to face. When there are exigencies that require tasks that must be performed for survival or for military success, the reserve capacities are enormous.

Stress — there is no one type.

LEE: As soon as you start talking about tolerance, which is work performance under another name, you come right up against the question of your ultimate objective, because what is tolerable to a union organizer is something slightly different from what a hard-bitten Army commander will tolerate. These different concepts of tolerance are admissible in their own place and their own time. This is an elastic scale against which we have to measure things; but, fortunately, there is another elastic scale concerned with factors which determine an ability to continue to perform. This ability increases with the severity of the stress that you are up against. Sensations of discomfort are important industrially, and they are also about the only things you can readily assess. Bad as the measure of sensation of discomfort obviously is, statistically it pans out fairly well.

After you have gotten to a certain degree of discomfort, more of it doesn't count too much, and you move into a realm where, both industrially and physiologically, you have to deal with another set of measurements. Fortunately, in this region, sweat loss is a good measure, but again you come to a ceiling. Then you move into another area where changes in rectal temperature or heat storage (which is another aspect of the same thing) become a useful measure. Finally, you move into the area with which people at Fort Knox were concerned — the question of survival. Each of the measurements one uses is only a very partial view of what is going on inside. While it is comforting to have a concept of an over-all strain placed on the individual, for various reasons, you never get a full look at it. You can look only at a very small portion of it, under rather peculiar and limited circumstances.

How you can get from this extremely limited series of points of view to an actual over-all strain is a matter of considerable argument. We shall not start the argument here, but I did want to bring out the point that all of us are forced to talk about different things at different times.

High-calorie vs. low-calorie.

WELCH: In conditions where the temperature is —10° F. or so, a minimum of 4400 calories is required. I am sure that many times the temperature at Ladd Air Force Base was —40° F. outside Dr. Rodahl's window, but he was not out there to enjoy it. So we would agree with the bottom half of Dr. Johnson's chart. Dr. Buskirk and I have a paper in press that goes along with the idea that temperature in the properly clothed man is not critical, whereas the workload as well as the weight of the individual seem to be the crucial factors. At —40°, and with the assumption that the castaway is not properly clothed, I wonder if 4000 calories is actually enough for him. We had men working hard — and by that I mean pulling sleds around 10 to 12 miles a day, two-man sleds — and the men consumed daily an average of around 4163 calories for a period of three weeks.

JOHNSON: Actually, I have very strong feelings on that. I think the battle between the high-calorie versus the low-calorie advocates has been going on ever since I can remember — certainly back in 1939 when I first got into the Army. You will find precisely this: The Food and Nutrition Board people, with whom I go along on nutritional matters, say you have to put in a factor of safety to take care of the big fellow, the fellow who will do a lot more work, the pregnant woman, the injured person, and so on. You have to put in an extra safety factor in the recommended allowances. Some of my colleagues would say, "Let's forget about these fellows. Let's take the mean, and then go down a couple of standard deviations. In this way we arrive at the minima, or the other way at average values plus a bonus."

Tests — which ones are useful?

SPECTOR: Now, going back to the principal goal of the conference, I would like to ask your cooperation in focusing attention on methods — what they tell us that is useful, what they do not tell us, what are some of the fallacies that may lead us into errors of judgment. We need an evaluation of the tests we have heard described. Which tests can we afford to drop? Which should we emphasize? which are the new tests at which we should perhaps take a closer look? Does anyone care to start the ball rolling by commenting on the various cardiovascular tests which have been mentioned, with the idea of pointing out those tests that have really been useful. At the same time you need not hesitate to point out some of the deficiencies.

As an example, It has been emphasized that pulse rate is a very useful measure. The data of Dr. Young confirmed this. But there is one confusing thing — instead of getting an increase in pulse rate as the stress of dehydration progressed, we got a decrease. One explanation is that starvation was coming in, due to restricted water, and associated with starvation is bradycardia. This raises the question, then: How useful under such circumstances is pulse rate?

Dr. Henschel mentioned yesterday the Utopian need for an integrated index. This is going to elude us for some time to come, and we may never be able to achieve it. We have to look at performance from various points of view. How do you combine the results that you get from these various approaches? Perhaps each one of us might answer these questions somewhat differently, depending upon what we are measuring and why. I would like now to invite discussion along these lines.

ELMADJIAN: Under various conditions, tissue responsivity begins to change. Some of the data given by your group, Dr. Young, made this particular thought come to me — that tissue response was being changed by by a change in the milieu, the sodium, the electrolyte balance. You may have the same stimulus, but you will not get the same response. Changes in the milieu cause changes in the response of that tissue or organ. The system that you may measure — and it may be the sympathico-adrenal, the adrenal-pituitary, or some other system — may or may not change in itself, but you do begin to get shifts in the sensitivity and in the response. I will explain this in reference to one test that Robb, in Vermont, did. When he gave a steroid like DCA and changed the electrolyte balance in the system he began to get (for a given dose of noradrenalin) far greater responses in the cardiac system. We have to think about this when we try

to evaluate a response test as a load test.

BROŽEK: I shall comment not about a specific test or tests but rather about the theoretical framework within which the questions must be posed. What are the criteria which we can apply in evaluating different kinds of tests? They are at least three, and you may add some others.

One, *consistency*. If you are measuring something and there is no evidence that this something has changed, you must come up with the same kind of an answer. In other words, for all kinds of biological tests we should have, as part of the description of the tests, data on the reliability with which the particular measurement can be repeated under specified conditions in specified populations. The specification of the population is very important because, as all of us know, the degree of correlation between two sets of repeated measurements depends in part on the range within which a variable is measured.

The second point is *specificity*. You do not want to measure (at least it would be uneconomical to do so) the same aspect of the response by different techniques. Consequently, if we see that ventilation, pulse rate, plus some of the other aspects studied by Dr. Balke, are changing in the same ways, obviously it is uneconomical to measure all of them. Specificity is our second criterion in the evaluation of any measurement.

The third and most important criterion is *validity*. This is the crux, and I feel that this conference has not really scratched the surface at this particular point, which is of central importance. We have all kinds of validity. Firstly, a sort of superficial "philosophical" validity. We say, all right, this is what we are measuring, and we think it is a useful thing to measure. It means something because we think so. Secondly, we may assign the validity to a measure, if the changes in this function indicate biologically significant impairment of homeostatic mechanisms which eventually will bring us to the realm where the deterioration changes into a clinical disease.

We may use the changes that take place under the impact of different stresses as measures of the usefulness of a test. Here I speak of test *sensitivity*. Performances in a test change under one set of conditions, and do not change under other conditions. We may define the stresses in objective terms such as the cumulative negative caloric balance, and against this objectively defined background we evaluate the sensitivity of this or that particular test. I believe that this is the theoretical framework against which, in the end, we have to consider each and all of the variables about which we have been talking here—not in the next 15 minutes but eventually.

JOHNSON: I agree with Dr. Brožek. Validation of a test is a tricky business. When you have devised a test, there is a temptation to conclude: "This man is good because he gets a big score in my test." I have fallen, personally, into this trap.

BASS: There is one group of men who have a greater known physical performance capacity than the average — the well-trained athletes. I would suggest that we have overlooked the epidemiological approach that my former colleague, Harry Danvers, used to advocate — that is, to try to find out what basal physiological differences exist between well-trained athletes

and the majority of the population, differences that could reasonably be correlated with predicted performance ability. For instance, one thing that I didn't hear mentioned here is the relation of the blood pressure to change in posture. That would be just one type of example. It may be that some simple physiological measurement might provide us with something that we are looking for.

BROŽEK: I agree with Dr. Bass. I have in my notes, as one of the criteria, the physiological differentiation between individuals in different states of clinically assessed health and fitness, and in disease.

TAYLOR: I think you have to be a little careful there. When we talk about athletes, we should add the effects of a conditioning program. The differences between athletes and the rest of us may be due, in part, to selection before the individual ever gets started being an athlete. I believe fitness tests have to be sensitive to the effects of training, also.

LEE: I would like to add one thing there, too. You cannot speak meaningfully of performance capacity in general. You must speak of performance capacity for *what*. Even if you are considering physical performance, you still have this question of "performance for what." During World War II, young, active, quickly reacting people were chosen for training as pilots. The technique used was very successful. The same technique was used for selecting the crews of the Armored Corps in the British Army. It proved to be a mistake, because they were being called upon to face two entirely different kinds of situations. The pilot faced situations calling for rapid judgments, with high stress but over a short period of time, whereas the tank people were being called upon to face a difficult, dangerous, infuriating position for three weeks or four weeks at a time. The 17- and 18-year-olds didn't face up to that, whereas the 24- and 25-year-olds who in pilot-selection terms would not have been near the optimum, were the optimum for the Tank Corps of operation.

TAYLOR: I think it is essential to emphasize what Dr. Lee and Dr. Brožek have said, that we have to start out by analyzing the task that we are going to study and break it down into its component parts and study the factors limiting performance of the specific tasks.

SPECTOR: In line with the idea of the effects of training or conditioning and the dramatic differences between athletes and non-athletes, there is the parallel consideration of measures of performance that is appropriate when there has been opportunity for a certain amount of adaptation. Frequently you have to use different measures, different tests, to get the information desired under those two conditions.

Required: A knowledge of all the parameters.

CRAIG: My reaction to this meeting is that as scientists we should try to accumulate information and deepen our theoretical grasp so that we can handle more effectively the problems that may come up. That is, we should have a background of knowledge on all the parameters of performance. At the same time, if there is a specific military problem that you are confronted with, considerable attention should be given to finding a direct solution to it. If you are concerned with under-nutrition, some thought should be given to just what form this might take in the field — and then set up a situation in the laboratory to duplicate it, have people

perform, and see what happens. We should not forget that way of getting at the problem.

TAYLOR: When we started this conference, I made some remarks to the effect that the laboratory devices we employ allow us, we think, to put stresses in rank order on the basis of the degree of deterioration they produce. But to be certain of one's results, if the problem is practically important, you have to take the laboratory device into the field and put it into the practical situation. This is the other side of the coin that Dr. Craig has been talking about.

SPECTOR: One of our urgent needs is to establish a glossary of terms. Some of the confusion in the literature comes from the fact that we are using different terms when talking about the same things. The sooner we establish a clear-cut terminology, words that have the same meaning to all of us, the sooner we shall be able to compare results that we obtain in our various laboratories.

VOGEL: There has been much talk about performance capacity under stress, and no discussion whatever about performance capacity and prediction in the face of boredom and long periods of monotony. I should like to hear discussion along these lines, because the future will show that we will be faced more and more with performance under monotony and boredom. We will have human beings in submarines or in space satellites, just sitting out there and watching and listening. How will we be able to predict performance under conditions such as that? Or, we may have submerged Texas towers — people just sitting day after day, listening. Certainly these are not stressful situations as we usually think of stress — but boredom and monotony are stressful.

BROŽEK: You are touching here upon another very serious stress, the one that involves sensory deprivation. The work that has been done on it shows that this is a serious stress, one where, actually, if the sensory deprivation is complete or almost complete, you may develop under certain conditions psychotic alterations within a matter of hours.

SMITH: It is in this area of stresses peculiar to the industrial civilization that the physiologists should appreciate the fact that performance indicators may be at present the only guide, at least initially, for picking out the variations, even minor ones, introduced by a particular individual in the specific task. We know that in industrial jobs characterized by highly repetitive types of work (work that has been fractionated into a few repetitive operations), the assessment of possibly adverse conditions must depend largely upon the performance itself. One goes on from there to introduce either job enlargement programs or an enrichment of the social environment or alterations in the physical environment or other change in the nature of the task in order to determine the factors operating in the situation. It is in this particular area, I think, that people have to appreciate the general nature of the problems of human work. It is here that a joint effort by physiology and psychology, in time, is going to make a real contribution not only to military problems but also to industry. This is a very real problem in industry today — the deadening, sustained stress in the industrial worker.

BROŽEK: I am very glad Dr. Vogel brought out this problem; it opens a whole new dimension of stressful conditions.

CLARK: Are we thinking now in terms of what Dr. Lee mentioned a few minutes ago; namely, selection? We have not been thinking at all in those terms. Must we now bring in all of these other aspects?

SPECTOR: Who would like to comment on that? What is there that individuals interested in changes under stress can learn from those who have been concerned with selection?

BROŽEK: I think that the science of human work is a single pie out of which we cut, individually, a particular section. We are either professionally responsible for that sector or it is of particular research interest to us. Problems of selection are relevant and may influence the choice of test procedures used for the study of stresses.

CLARK: If that is the case, then we will need to bring an additional group with more varied interests to the next conference. Our representative has data only to cover performance capacity.

SMITH: May I comment briefly on this to see if we can go a little further along this line? It has been my understanding that we are not primarily interested in selection in this conference. The conference was directed toward the examination of the functional reactions of the human organism, particularly in work, and in other connotations of "stress."

SPECTOR: This is the position, exactly. But what I intended by my remark was merely to indicate that perhaps the same technique could be used for selection for those who are interested, and vice versa.

LEE: As one who brought selection into this, I was simply using selection as an illustration of the fact that there are different attitudes toward what you consider a performance test and what you expect from it.

BROŽEK: And let us not forget, let me repeat, that some of the criteria that we develop in the process of selection can be legitimately applied in the evaluation of the stresses.

BALKE: Let's consider one practical example. In the Air Force now we are having an increasing number of so-called neurocirculatory collapses at relatively low altitudes. You may not know that a pilot who faints just once is through — no more flying for him. That is the present Air Force regulation. Now, since training this man costs $250,000 in the first place, is there real justification to throw him out, to ground him? If I would get such a man for appraisal I would not only test his work capacity, which is just one facet, but I would probably run him through a battery of stress tests — including hypoxia, and so on.

If I had to investigate work of long duration I would change my testing procedure completely. I would go to a steady-state type of work which in this testing procedure might require a pulse rate of 150 or so for six hours, and I would try, for instance, to get the respiratory quotient. In steady state this is an expression of what is being burned.

We consider a workload yielding a pulse rate of 180 very dangerous. Our cardiologists insist that we take an ECG at the same time because we might run into a coronary patient. But before I evaluate the ECG, just by looking at the physiological measurements, I know that the man has to be taken off the treadmill test. His pulse is increasing, oxygen intake is increasing, pressures are increasing to a certain degree before they level off.

In research we have to do our looking and listening in order to find out the simplest means of fitness appraisal. I don't measure oxygen intakes any more because I can predict them much easier. I have to take the pulse rate. What we should get is the cardiac output, which tells us everything. But there is no easy way of measuring the cardiac output, at least not routinely. You can get it once in a while in light or moderate workloads, but you can't get it routinely in severe workloads.

Work capacity, in the last analysis, is the quantity of the possible metabolic exchange. We could use anything which increases the metabolic rate besides work if we could get such increases as we get with physical work. Now we are using the treadmill or the bicycle ergometer because it is a reliable piece of equipment that gives us, under constant conditions, consistent results. There is no other means by which you could increase metabolism to 15 or 16 or 17 or 18 times the basal value. So this gives us the entire range of work capacity, and I don't know of any better way of getting at the problem.

I was asked this morning by Dr. Elmadjian what would happen if I would superimpose a new stress situation on this walking test. If you have a very well trained man and you expose him to heat conditions, he will stay on because his work capacity and the available reserves will enable him to tolerate the heat stress for a considerable length of time. However, if the individual's work capacity is low, so that this type of work would be close to his capacity, then the additional heat stress which now diverts the blood that should go through the muscles to the skin, in order to get the temperature regulated, of course will reduce the total work capacity.

SPECTOR: Before we close I wonder whether Dr. Henschel and Dr. Allison would like to say a word.

HENSCHEL: I shall be brief but I still have a concern. We can use a variety of tests to characterize what the individual is capable of doing at the time you are giving him the test. There are many types of tests. You can go all the way from the biochemical and physiological to the psychological tests which will tell you what the person is capable of doing now. That's fine. But in real-life situations you can't spend two days characterizing the man. One would like to have some type of index that you could apply on a wide basis to separate in broad categories men's performance capabilities: "These are poor performers; these are people who won't get into trouble; these people will be your good performers." I don't feel at the moment that many of the tests and things we are working on and are using are actually geared to give us the type of information that eventually will allow us to develop the needed simple index for purposes of prediction.

ALLISON: Dr. Spector, I would like to take this opportunity, while we are all together, to express the appreciation of the Subcommittee on Nutrition for the privilege of sponsoring this conference. The members of the Subcommittee have felt for some time that what we are talking about and have talked about in the past two days is the type of discussion and the type of science that we need to push. We hope that out of this conference will come a more vigorous and integrated approach to the solution of the problems that we have been discussing.

EPILOGUE

ASSESSMENT OF PERFORMANCE CAPACITY: AN EPILOGUE

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Why an epilogue?

The aim of the symposium was to review and evaluate methods for the assessment of performance capacity and their application in certain situations. Thus the intended coverage was comprehensive in regard to methods, selective with reference to the specific areas of application. This very goal is not invulnerable to criticism by the purist. He may wish to insist, resolutely, that methods for the appraisal of performance capacity must take into account the specific conditions being studied, not only in regard to the organ systems and functions that play crucial roles as factors limiting performance but also because their measurement must be adapted to the particular test conditions and the experimental regimen.

This, rigorously speaking, is true. Let's consider for a moment the use of standardized questionnaires designed to assess alterations in well-being under stress. This approach may be highly relevant and fruitful under certain conditions while it will be totally inappropriate, inapplicable in other situations. Furthermore, there will be substantial differences in the specific features of the questionnaires, such as the number of items, the number of steps or degrees used in rating the "deviations from normal," the content (i.e., the characteristics to be rated), the frequency with which the questionnaire is being administered during the period of observation, etc.

Although the close interdependence between conditions under which the observations are to be made and the procedures to be applied cannot be denied, there is merit in taking a look at problems of fitness and performance capacity appraisal from a greater distance. In this perspective the minutiae disappear and only the major outlines of the problem remain visible. It was this kind of a perspective that Dr. Spector and the present writer had in mind when the symposium was nothing more than a glint in Harry's eye.

His untimely passing unavoidably delayed the processing for publication of the symposium proceedings. Consequently, it appeared useful to add selected references to recent publications which bear upon the problems discussed at the conference. The methods for appraisal of performance capacity will be considered in a variety of contexts: in connection with environmental and metabolic stresses, including nutrition and drugs; exercise and sports; occupational work; aging; and disability and disease. In addition, we shall briefly consider some problems of terminology. In fact, it may be preferable to begin with the latter.

A bit of lexicography

Performance capacity is a hypothetical construct, that is, a state of the organism inferred from and characterized on the basis of a large array of

somatic, biochemical; physiological and behavioral variables. We may regard performance capacity as a "hypothetical state variable." Much as other hypothetical constructs, "performance capacity" has what is called "surplus meaning": it gives rise to measurable phenomena, including variables other than the observed ones that led to hypothesizing the construct (cf. 23, p. 116). Among these is the actual performance. This is, from the practical point of view, the most important "predictable consequence." The usefulness of the concept of performance capacity, and of the special set of operations on the basis of which it is defined, depend in the last analysis on the experimenter's ability to make valid inferences about the "job performance."

Information on physiological functions and metabolic states can not be readily interpreted in terms of the effects on "performance," even if the latter is specified, be it in biological (e.g., work involving sustained perception of small visual details) or in occupational terms (e.g., the performance of a radar-scope operator). In fact, the problem of validation of the criteria, proposed as measures of performance capacity, is one of the toughest the experimenter must face. Not infrequently, we must be satisfied with indirect, relative assessment, based on the comparison of various stresses studied in the laboratory and the results obtained with different intensities of a given stress. When available, clinical findings and field experience should be considered in interpreting the results of laboratory studies.

Since performance is rarely defined or studied in terms of measurable "on the job" activities, we usually measure those functions that are deemed *relevant* for such a performance, even though only rarely do we know with precision at which degree of deviation from the normal does this or that function become a factor limiting performance. In physiological laboratories treadmill walking or bicycle riding have been the favorite type of physical performance, with natural and heavy emphasis on cardiovascular and respiratory measurements as indicators of the organism's functional status.

In broadly oriented studies of stresses, a large spectrum of functions is sampled. These cover the major facets of a biologically defined "fitness." As a rule, the measurements are not validated against external criteria of real-life performances.

The term "performance capacity" is close to "fitness," at least to that meaning of the term fitness which refers to the search for measurable, biologically meaningful components of performance capacity sampled from the total range of human activities, from exhaustive muscular through finely coordinated sensori-motor to perceptual and intellective types of performance.

In the context of research on stresses efforts have been made (52) to develop batteries of general tests which would measure some of the basic components of a variety of performances. In this way it was hoped that a basis for broader inferences regarding the effects of experimental regimens on performance capacity would be provided than if tests of cardiovascular, respiratory and metabolic processes, or tests of sensory, motor, and intellective functions and verbally mediated indicators of well-being and other criteria of personality were used alone. Separating the study of man into hermetically closed compartments of human morphology (physical anthropology), biochemistry, physiology and psychology seems to make little sense in considering man's ability to withstand physical and biological stresses and in appraising the effects of these stresses on potential performance, i.e., on work capacity.

In addition to (and, sometimes, instead of) the non-specific, general indicators of fitness, the characterization of stress effects may call for inclusion of criteria specially relevant to a given situation. Thus, measuring skin and deep body temperatures is relevant under conditions of thermal stress but would not be a fruitful measure of individual biological differences, especially if measured at rest, in the capacity to navigate an airplane on a long and strenuous mission. To take a metabolic characteristic, measurement of the concentration of pyruvic acid in plasma makes good sense in thiamine deficiency but would yield little useful information in some other nutritional stresses.

The term "performance" is used at times as the equivalent of "function," and some authors speak of kidney, liver, or cardio-respiratory performance (cf. 37, 53). This, we believe, is an undesirable usage. In the recommended terminology these are "functions" of organs and organ systems. Some of them may be appropriate — under specified conditions — as indicators of the performance capacity of the human organism in motor (muscular, neuromuscular, psychomotor), perceptual, and intellective tasks.

General sources of information

No specific volume of the informative series entitled *Methods in Medical Research* (The Yearbook Publishers, Chicago) has been devoted to the topic of a comprehensive fitness appraisal but several of the 8 volumes that have been published between 1948 and 1960 contain relevant sections. Thus, pulmonary function tests were described in Vol. 2 (J. H. Comroe, 1950). D. Mainland covered modern development in statistical methods (in Vol. 3, 1950) and R. G. Daggs edited the section dealing with the methods used in environmental research (also in Vol. 3). Several volumes deal with the cardiovascular system (H. D. Green, in Vol. 1, 1948 and H. D. Bruner, in Vol. 8, 1960, blood flow measurements; R. Gorlin and J. W. Warren, hemodynamic methods — heart and lungs, in Vol. 7, 1958). R. W. Miles edited a section in Vol. 3 on Selected Psychomotor Measurement Methods. This important contribution (43) to the literature on the appraisal of performance capacity in the laboratory setting consists of 6 sections: 1) physical work and strength tests (bicycle ergometer, hand grip), with a note on the evaluation of static equilibrium; 2) reaction time (simple reaction time, reaction and coordination, speed of response); 3) coordinated motor responses (tapping, mirror drawing, pursuit movements); 4) manual dexterity, (finger dexterity, hand tool dexterity); 5) eye-movement coordination; and 6) motor tests for laboratory animals.

In experimental psychology, a variety of methods was described by Andrews (3) and the collaborating scientists. There is no section on "performance" or "performance capacity," dealing with the specific problems and techniques relevant to the typically longitudinal studies on fitness, with their interdisciplinary orientation and numerous considerations not typically present either in experimental psychology or in the study of individual differences. But the interested reader will not come away empty-handed. The editor supplemented the text, which has references appended to individual chapters, by a bibliography of publications dealing with apparatus (4). The categories into which the references are classified include measuring and timing devices, stimulation systems, and apparatus dealing with "body activity," in addition to the special senses, perception, learning and memory, and others.

The use of apparatus tests in the Aviation Psychology Program of the Army Air Forces during the Second World War was described at length (1056 pp.) in a volume edited by Melton (42). The volume retains its value as a source book on psychomotor tests. These tests were developed or modified for the selection and classification of aircrew personnel rather than for the appraisal of changes in work capacity under conditions of stress, although some of them, at least, could well serve the latter purpose.

A treasure-house of information on "mental" measurements is represented by Buros' yearbooks, the latest of which reached the mammoth size of close to 1300 pages (16). It serves well the purpose of providing assistance in locating and evaluating tests.

Problems and techniques of personality measurement were presented systematically by Ferguson (24), Cattell (17a), and Guilford (30a). Specific techniques have been described in monographs. Citation of this literature would go beyond the framework of this brief "bibliography with comment." Recent textbooks in the general field of psychological testing are those of Anastasi (1), Nunnally (44), and Cronbach (22). An introduction to psychology, organized around the concept of human performance was prepared by Gagné and Fleishman (29). Especially relevant are the chapters on human abilities (pp. 90-141), discrimination and identification (pp. 178-218), and motor skills (pp. 219-262).

Nutrition

A broad spectrum of methods, applied in connection with a severe nutritional stress, was described in the appendix to The Biology of Human Starvation (35, pp. 1069-1118). In addition to methods of statistical analysis and the procedures used in clinical examinations, the appendix contains descriptions of methods for the characterization of man's physique, chemical analyses, physiological procedures, and a variety of psychophysiological and psychological tests, questionnaires, rating scales and other approaches to a quantitative and semiquantitative study of behavior.

The section devoted to physical anthropology dealt not only with the traditional measurements on the living and the more recently developed procedures of measurements made on photographs, using W. H. Sheldon's technique, but also with densitometric appraisal of the fat content, following A. R. Behnke (cf. 45) and a quantitative estimation of bone mineralization based on skeletal roentgenograms (40).

The biochemical procedures were concerned with urinary excretion of vitamins, nitrogen balances, determination of fluid spaces (blood, plasma, extracellular fluid), electrophoretic analysis of serum proteins, and semen analysis. These methods were fairly specific to a given stress. The more generally used procedures, such as hemoglobin or blood sugar determinations, were identified by reference in the text.

In regard to physiological functions, venous pressure determinations were described together with aerobic and anaerobic work tests, maximal oxygen transport (cf. 53), electrocardiography and miscellaneous other procedures (determinations of basal metabolic rate, pulse rate, blood pressure, respiratory rate, ventilation volume, and oral temperature).

In the section on special senses, tests for measuring visual and auditory acuity were briefly outlined, and procedures for determining the critical (fusion) flicker frequency were specified (cf. 49).

Voluntary motor (psychomotor) performance was studied in reference to strength, speed, and coordination (cf. 14). Intelligence was examined using power tests (without specified time limits), speed tests (with rigorous work limits), and tests of learning ability. A repeatable battery of intellective texts, specifically adapted for research on stresses (30), was described elsewhere in detail.

Personality was characterized on the basis of interviews, analysis of the diaries kept by the subjects, standardized personality inventories, self-ratings, man-by-man ratings, and complaint questionnaires as well as by projective tests (12, 36).

Methods for evaluating the adequacy of nutrient intake and nutritional status were the subject of a special symposium (50). Methods for the study of the impact of nutrition on performance were examined with reference to animals (J. Brožek, pp. 155-157; cf. also 58) and to man (J. Brožek, pp. 204-221). The latter paper considers the general problems of the appraisal of performance capacity; the value and limitations of data on actual performance; the potential uses of simplified replicas of complex types of performance (see also 13); and laboratory tests of locomotion, manipulation, perception, and intellective performance.

In the same symposium, R. E. Johnson (pp. 222-237) outlined a program for characterizing the response of the organism to nutrient intake in terms of nutrient balances; body composition; liver, kidney and endocrine function; and hematological criteria. These measurements were regarded as meeting the "criteria of pertinence," developed by the author and his colleagues. That is, according to their experience the measurements were predictive of potential deterioration, discriminative among nutrient combinations, and interpretable in terms of current clinical thought. The methodology used by Johnson and his colleagues at the University of Illinois is presented in their reports of studies on survival rations (47, esp. pp. 49-89).

Body composition, mentioned by Johnson as one of the useful criteria, was the subject of a round-table discussion, chaired by M. I Grossman (ibid., pp. 261-313), with D. E. Bass, A. R. Behnke, W. R. Best, and J. Brožek as participants; cf. 11).

Methods for the appraisal of physical fitness (the Harvard step-test and its modification), used in connection with the field appraisal of nutritional status, were incorporated into the manual prepared by Consolazio (19, esp. pp. E33-E48). The manual contains also detailed instructions for the measurement of energy expenditure by indirect calorimetry using the Mueller-Franz portable respirometer (cf. 20).

Effects of drugs

Experimental pharmacology and, to a lesser degree, therapeutic pharmacology, are also concerned with performance and performance capacity. Thus it may not be inappropriate to make reference to the proceedings of a symposium on the quantitative appraisal of drug effects (38). Dornhorst (ibid., pp. 11-15) briefly considered the present status of the measurement of pressures and fluid flows in man. Several procedures that were presented are relevant primarily within the narrower framework of pharmacological research, such as the measurement of the effects of drugs on the gastrointestinal tract. Of more general interest are the papers on the measurement

of muscular concomitants of emotion (P. Sainsbury, pp. 69-75), effects of drugs on performance (Hannah Steinberg, pp. 76-87) and motor activity (L. Goldberg, pp. 98-116).

There is a large and explosively growing literature on the effects of drugs on various aspects of animal performance and behavior (cf. 8a).

Physical exercise and athletic performance

The muscular, neural, metabolic, hematologic and cardiovascular aspects of physical exercise are discussed in introductory textbooks. Karpovich (34, pp. 278-290) devotes a chapter to tests of physical fitness, divided into 3 groups; a) muscular performance (more specifically: strength tests), b) organ function (pulse rate and blood pressure; vital capacity, breath holding, pulmonary reserve; oxygen consumption), and c) a combination of muscular performance and organ function.

An outstanding contribution to the science of athletics is represented by the collaborative volume edited by W. R. Johnson (33). It covers the structure and the mechanics of human motion and several other aspects, including considerations of sex, age, and therapeutic uses of exercise. Directly relevant is the large section on the physiological aspects, with E. F. Adolph's chapter on regulatory physiology (pp 67-79), H. L. Taylor's on energy expenditure (pp. 123-161), R. L. Riley's on pulmonary functions (pp. 162-177), L. Brouha's and E. P. Radford's on the cardiovascular system, R. Moore's and E. R. Buskirk's on body fluids (pp. 207-235), L. G. Wesson's on kidney function (pp. 270- 284), B. Balke's on work capacity at altitude (pp. 339-347), J. Duffner's and E. H. Lamphier's on underwater exercise (pp. 348-383), D. B. Dill's on fatigue induced by strenuous exercise (pp. 384-396), and L. Brouha's on training (pp. 403-410).

Dill points out that in strenuous physical exercise the degree of fatigue that is experienced by the subject depends on his state of fitness, and he devotes 4 short but tightly packed pages to fitness tests (pp. 397-400). Reference is made to a number of valuable wartime studies, some of which were published only as governmental reports, covering both athletic and physiological tests of fitness, and considering laboratory as well as field studies on fitness among troops.

Dill places on the record the devastating critique of the various fitness tests used during World War II, offered by W. B. Bean and his coworkers (7). These authors concluded that none of the tests was satisfactory for discriminating among degrees of individual fitness, even though several of the tests were acceptable as gross measures of fitness and as criteria for comparing groups. It may not be out of place to recall some of the specific criticisms levelled by Bean et al. (op. cit.) against the tests of physical fitness:

Failure to test chief components of fitness

Inadequate scoring system

Lack of reproducibility

Inability to control or measure motivation

Failure to consider physiological cost or post-exercise conditions

Contamination of test results by the changed work methods (acquired test skills)

Failure to consider environment or physique in scoring systems. While almost 15 years old, this "catalogue of sins" has not become obsolete.

Some of the topics discussed in the present volume or in the *opus* edited by W. R. Johnson were taken up also in the Colloquium on Exercise and Fitness, held in December 1959 (51). Thus B. Balke (pp. 73-81) described a method of testing the "biodynamic potential" of an individual, defined as "man's aerobic capacity for maximum functional demands" and measured in terms of the work stress at which the heart rate is raised to about 180 beats per minute. The majority of the Colloquium papers were concerned with applications: the effects of exercise (or the lack of it) and factors affecting man's capacity for physical work. Of general methodological interest is R. B. Cattell's analysis of some psychological correlates of physical fitness and physique (pp. 138-151).

European, especially German, literature in the field of exercise, concerned both with the physiological and clinical aspects, was summarized by Hollmann (31). A special section in the book is devoted to the methods for the appraisal of circulatory and respiratory functions (pp. 10-21). Particular attention is paid to the "spiroergometry," with respiratory and metabolic measurements made at rest, during work, and during recovery. In German laboratories bicycling and cranking ("Drehkurbelergometer") are favorite forms of graded work stress.

The criteria of performance capacity are considered by Hollmann also in connection with the evaluation of the effects of training (pp. 104-116), including maximal oxygen consumption and the "latent (spirographic) oxygen deficit," determined under steady-state conditions of light physical work by switching the respiratory intake from the room air to pure oxygen. The author designates as "physiological performance limit" the intensity of physical work that can not be increased without resulting in a spirographic oxygen deficit (p. 108).

Work

A textbook of industrial physiology, growing out of the rich treasure of experimental investigations carried on over a period of years at the Max-Planck-Institut für Arbeitsphysiologie, in Dortmund (Germany), was prepared by Lehmann (39). The section on performance capacity (pp. 85-90) is brief but other parts of the book and of Ch. 2, dealing with the premises and consequences of work performance, provide supplementary information (cf. the section on sex differences and age trends, pp. 90-98, or on the physiological work curve and biological rhythms, pp. 98-105). In the footsteps of Max Rubner and Erich Atzler, the German school of industrial physiology paid a great deal of attention to energy expenditure. It is hardly surprising that Lehmann devotes a large chapter (pp. 122-164) to the energetics of the human body, including the problems of measurement. The apparatus (p. 130) for the determination of energy expenditure during occupational work, developed at Dortmund, has been widely used.

No modern systematic presentation of industrial physiology is available in English. Brouha's recent monograph (9) does not attempt to cover the whole field. But the limitation of breadth is fully balanced out by the depth dimension and the fact that the author speaks from first-hand experience: much of the material represents the results of plant surveys and laboratory

experiments conducted by the author over close to 2 decades. The volume deals with the worker, especially the cardiovascular responses to physical work; the physical environment, with focus on the heat stress; evaluation of the physiological requirements of jobs; and the evaluation of improvements designed to lessen stress and fatigue, with heavy reliance on heart rate as the criterion.

A crossectional portrait of "ergonomics," defined as the interdisciplinary study of the natural laws of human work, was presented in the second volume of the Proceedings of the Ergonomics Research Society (27). The problems of human work were approached from the point of view of anthropometry, physiology, and experimental psychology. In experiments on clothing (M. Nielsen and L. Pedersen, pp. 59-66) the rectal and skin temperatures were measured in human subjects. P. O. Åstrand (pp. 69-77) summarized the data presented earlier in a monograph (5); the characteristics measured included maximal oxygen intake, heart rate during work, blood lactic acid concentration, lung ventilation, maximal working intensities (speed of locomotion maintained for about 5 minutes), and mechanical efficiency. The behavioral studies reported in the proceedings dealt with visual perception and problems of movement and force.

In America the term "human engineering" won popularity as the label for studies on the interaction between man, machines, and work environments (41). The methodology of research in human engineering was presented by Chapanis (18). In addition to such general topics as the nature of experimentation, including a chapter on "some special problems in experimenting with people" (pp. 208-252) and on statistical methods, and some very special procedures (methods for the study of accidents), the author describes the methods of direct observation, psychophysical methods (measurement of absolute and differential thresholds), and articulation testing methods originally devised as means of appraising the effectiveness of telephone communication. This is a relatively narrow spectrum of methods, a presentation of human engineering largely from the psychologist's point of view.

By contrast, the collection of reviews edited by White, Lovelace, and Hirsch (55) is concerned with the biomedical (biophysical, biochemical) aspects of performance. The advancements in instrumentation, analytical techniques and methodology are considered with specific reference to studies on the human factors in flight. Three papers describe various aspects of respiratory physiology: spirometric methods used to determine total lung capacity and its components, oxygen consumption, carbon dioxide output, and the respiratory quotient (U. C. Luft, pp. 8-22); automatic methods for the analysis of respiratory gases, based on a variety of physical principles (C. S. White, pp. 125-167), including quantitative emission spectroscopy (C. S. White and W. R. Lovelace II, pp. 253-268); and methods for sampling expired air (N. P. V. Lundgren, pp. 269-276). M. A. Palmer brought out the value of high-speed motion picture photography as an aid in biomedical investigations (pp. 23-38) and F. G. Hirsch (pp. 113-124) presented recent developments in temperature measuring techniques. In his presentation of methods and apparatus for the study of stress reactions and metabolic changes, B. B. Longwell (pp. 45-58) directed his attention to the endocrine system, intimately involved in the maintenance of homeostasis, and the regulation of water and electrolyte balances.

Fatigue

Light and prolonged or brief but strenuous activity results in a decreased ability to perform a given task. When work decrement can not be observed, either for technical, methodological reasons or because diminished performances capacity is compensated by increased effort, we must rely on studying the functional changes taking place in the course of work or make comparisons of the organism's status before and after work. The latter approach was used in the extensive researches on interstate truck drivers (32). The psychomotor functions were studied very thoroughly, though visual functions (glare tests, flicker fusion frequency, eye movements) were also included in the test battery. Hematological studies were limited to leucocyte counts. Potassium and total base in blood serum were determined.

For a review of the problems of fatigue as seen at the close of World War II see Bartley and Chute (6). True to the Society's interdisciplinary frame of reference, in the Ergonomics Research Society's Symposium on Fatigue (26) both the psychological and the physiological approaches were represented. The 20 papers constituting the proceedings of the Symposium represent a useful summary of facts and procedures.

A comprehensive survey of the literature on fatigue was prepared, in French, by Bugard (5). Although the circle of potential readers is limited, it may be of interest to register the publication of a recent Russian volume on the physiology of fatigue and recovery (28).

Heat and cold

The responses of the human body to thermal conditions, varying in both the positive (heat) and negative direction (cold), studied in the laboratory and in the field (influence of climate), were described by Winslow and Herrington (56). The authors took into account the protective influence of clothing and air conditioning. The relation of thermal conditions to work performance was considered (ibid., pp. 176-181).

The physiological and pathological effects of exposure to low temperature were treated in a monograph by Burton and Edholm (17). Especially relevant are the chapters on the appraisal of the thermal insulation of the body (Ch. 5), vascular reactions (Ch. 8), metabolic responses to cold (Ch. 9), and acclimatization to cold (Ch. 10), with a section on cold tolerance. Tolerance to cold may be appraised by measuring the time elapsing from the exposure of a subject to a given temperature to the appearance of shivering or to the voicing of complaints of discomfort, and by registering the changes in the response of the body (such as skin and rectal temperature and circulatory functions) during exposure to a standard cold stress.

The volume was considered important enough by the Soviet scientists to have it translated almost immediately into Russian. It was published in Moscow in 1957 by the Publishing House of Foreign Literature, with an introduction by I. S. Kandror. The text was translated by N. A. Kraskina.

Problems of performance, with special reference to the functioning of hands, were considered at a conference sponsored by the Subcommittee on Hand Functioning and Handwear (Committee on Environmental Protection, Advisory Board on Quartermaster Research and Development, National Academy of Sciences-National Research Council; 25). Most directly relevant are the papers by E. R. Dusek (Effects of temperature on manual performance, pp. 63-75) and A. W. Mills (Tactile sensitivity in the cold, pp. 76-85).

Aging

While changes in performance capacity associated with advancing years during maturity and old age are very slow at first and hardly noticeable, the cumulative impact is large (as far as the amount of deterioration is concerned) and profound (when measured in terms of the components of fitness that are eventually affected; cf. 10, 48).

The assessment of aging was one of the principal topics at the Conference on Planning Research on the Psychological Aspects of Aging (2). At the conference a special session was devoted to functional efficiency, skills and employment (ibid., pp. 227-226).

Although the voluminous handbook edited by Birren (8) has the subtitle "Psychological and Biological Aspects," the biological considerations are focused primarily on nervous function. Metabolic and physiological changes associated with aging are considered only briefly and with special reference to morbidity (p. 351), to brain metabolism and brain function (p. 458), and to effects of continuous exertion (p. 566). On the other hand, the psychological characteristics related to performance capacity are treated in detail (A. D. Weiss, sensory functions, pp. 503-542; H. W. Braun, perception, pp. 543-561; H. E. Jones, intelligence and problem-solving, pp. 700-738). A large chapter is devoted also to psychomotor performance (pp. 562-613). Its author, A. T. Welford, has summarized *in extenso* the important studies carried out between 1946 and 1956 by the Nuffield Unit for Research into the Problems of Aging, attached to the Psychological Laboratory of Cambridge University (54). Data on work performance were presented in Birren's *Handbook* by J. E. Anderson (esp. pp. 776-786).

The third volume of the Ciba Foundation colloquia on aging was devoted specifically to problems of methodology (57). K. J. Franklin's report (pp. 51-59) on reactions of organs to standard stimuli at different ages represents the typical physiological point of view but the reported studies were limited to thyroid and kidney function in animals. F. Verzár (pp. 60-72) stressed the value of studies on adaptation, defined as "the general capacity of organisms to live under continuously changing conditions," as a method of gerontological research: when the adaptation capacity of fluent metabolic equilibria begins to show deterioration, aging begins. Reference is made to animal studies on age decrements in the capacity for heat regulation (heat production in the muscles, heat dissipation) and in adaptation to low oxygen pressure.

The methods used in studies on the functions of human organ systems were described in the Ciba Foundation colloquium by M. Landowne (pp. 73-91), with emphasis on cardiovascular physiology. The paper contains a well documented discussion of the vexing problems of sampling in gerontological studies and of defining "normal aging."

A. T. Welford (pp. 145-169) examined the methodological problems involved in the study of changes in human performance with age. The author feels that the subject matter, including the methods of sampling, is so complex that seldom, if ever, can definite conclusions be drawn from a single laboratory experiment or an industrial study. But he does not advocate methodological nihilism. The complexities of human capacity can be reduced to a manageable number of variables; the brief laboratory experiments can be supplemented by studies carried out in industry; motivation of older

subjects is not regarded as a particularly serious problem; and the background factors affecting the comparability of subjects differing in age can be controlled. Welford favors small-scale investigations in preference to large-scale investigations with their rigidly standardized (and thus inflexible) methodology. I. Lorge (pp. 170-187) points out that further progress in the appraisal of the psychological aspects of the aging process depends importantly on the development of additional and better tests for psychomotor behavior, cognitive processes, and personal adjustment.

Disability and disease

In connection with researches on neuromuscular and sensory disability (21), W. B. Haber (pp. 14-24) compared tactile thresholds in the intact limb and in stumps resulting from unilateral above-elbow amputations, using 3 criteria (light touch, two-point discrimination, and point localization). The skin on the stump exhibited significantly higher sensitivity (lower thresholds) for tactile stimuli in regard to all 3 criteria. More directly relevant to the appraisal of performance capacity is the analysis of locomotor performance using a force-plate combined with stroboscopic photography and electromyography (M. Marks and G. G. Hirschberg, pp. 59-77). Drillis (pp. 86-109) described biomechanical analysis of gait in terms of temporal (time patterns), kinematic and kinetic criteria.

Numerous procedures were described and some methodological problems were discussed in the framework of the First Wisconsin Conference on Work and the Heart (46). The Conference was concerned, among other things, with the influence of work, exercise and stress on the normal and the diseased cardiovascular system. It was only natural that the working patient with a cardiac disease was in the center of attention, with R. A. Bruce et al. (Ch. 16) discussing a physical fitness index of tolerance for standardized exercise, based on considerations of duration of exercise (endurance), respiratory efficiency, and recovery heart rate; H. K. Hellerstein and Amasa B. Ford (Ch. 14) dealing with the energy expenditure of factory workers with heart disease and reporting observations on various physiological parameters of cardiovascular function — blood pressure, pulse rate, respiratory rate, oxygen utilization, electrocardiographic changes — under actual working conditions; and L. W. Eichna (Ch. 9) emphasizing the importance of hemodynamic measurements for the differentiation between circulatory congestion of cardiac and noncardiac origin.

Some relevant chapters can be found also in Section IV devoted to problems of work classification, including the estimation of work capacity on the basis of exercise tolerance test: (T. V. Paran et al., Ch. 38, esp. p. 333) and the assessment of the energy costs of industrial operations (A. M. Jones, Ch. 46, esp. p. 402).

In the section on Clinical Physiology M. L. Landowne (Ch. 15) reported on the use of tests of cardiovascular function in older, working subjects, studied both at rest and during exercise; G. E. Burch (Ch. 17) examined the influence of hot and humid environments; S. Wolf (Ch. 18) compared the effects of emotions and exercise on cardiovascular functions; G. Biörck (Ch. 20) considered laboratory tests for the appraisal of physical fitness and the use of physiological tests, including electrocardiographic exercise tests in neurocirculatory asthenia (Ch. 19); L. A. Brouha (Ch. 21) described the effects of muscular work on the heart, with special reference to the heart rate, presented examples of the specific demands made on the heart in

various occupations, and referred to a device (Ch. 22) for measuring forces involved in performing movements; M. J. Karvonen (Ch. 23) reported on researches concerned with the effects of athletic activities on the heart; and W. C. Kubicek, F. J. Kottke and Jean N. Danz (Ch. 25) summarized the results of their studies on the effects of various hospital activities in the rehabilitation department.

The presentations made at the conference on Work and the Heart constitute, in their totality, a well documented portrait of physical performance capacity appraisal, be it within a specific, limited context.

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